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JULY 25, 2015

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ScienceNews



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COVER Scientists are exploring new ideas about timekeeping in our brains, the evolution of biological clocks and time's direction in the universe. James Provost

Putting time's mysteries in order



A tick, a tock, a swiftly shifting digit. We have many ways of keeping track of time. We parse it into years, months, days, hours, minutes, seconds. We mark its movement obsessively, plan our days around it, use its form to bring meaning to stories with a beginning, middle and end (chronologically is one of our most common ways to organize information).

Cells use time's rhythms to organize different functions. Precision timing of neurons and muscles, directed by the brain, controls the body's movements. Time is a tool that brings order to our lives. It is ironic, then, to discover that physicists explain time as a product of disorder: Its forward direction reflects the unalterable tendency to increasing messiness in the universe.

Investigating both the orderly and disorderly dimensions of time provides the focus for this special issue, aimed at offering new perspectives on something most of us take for granted. On Page 15, for instance, Andrew Grant explores a fresh idea to explain the one-way direction of time's flow, a conundrum

that has perplexed physicists for over a century. The new proposal suggests that the universe actually does run backward as well as forward in time (as our brains would perceive it).

As it turns out, our brains' perception of time is quite complex, as Laura Sanders reports on Page 20. She describes the presence of multiple timekeepers in the brain and explores some of the troubles scientists face in studying how the mind pieces together data from its many timepieces.

On Page 24, Tina Hesman Saey's feature on biological clocks takes an evolutionary perspective, updating readers on new efforts to explain how and why circadian rhythms might have evolved in living things to begin with. Minimizing exposure to threats in the environment such as ultraviolet light and oxygen may have fueled the development of internal clocks. So too might have the cell's search for efficiency — saving energy by doing things in bursts, instead of continuously.

As our timeline of timepieces on Page 19 illustrates, the human ability to track time grows ever more precise, as does our understanding of how time's nature influences our world, brains and bodies. But many mysteries endure. And probably will for a long time. — *Eva Emerson, Editor in Chief*

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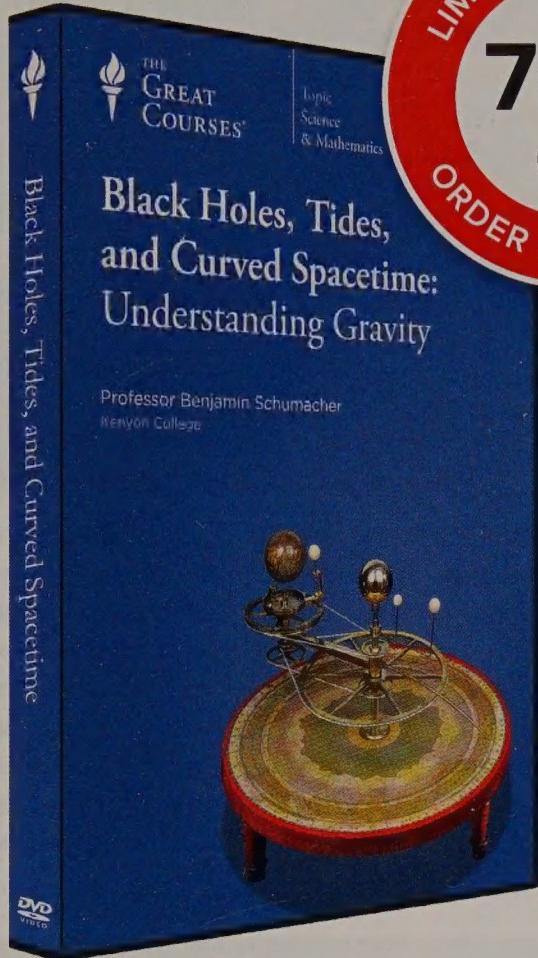
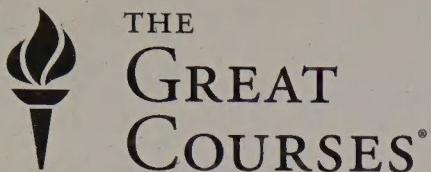
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Excerpt from the
July 24, 1965, issue
of *Science News Letter*

50 YEARS AGO

Firefighters pack fire-finding pistols

Firemen may soon be packing pistols to help them discover hidden fires. The pistols are new heat-seeking devices known as infrared detectors that sound a signal in the presence of a flame, ember or other abnormal heat source.... In actual tests, a fireman used one such device to find smoldering rags behind a huge metal wall cabinet.

UPDATE: Though not always pistol-shaped, infrared gadgets have been widely taken up in recent decades and now regularly help firefighters spot clandestine flames. Infrared technology also allows responders to find survivors through thick smoke and detect heat from fires through walls and doors. Some of the gizmos can be helmet-mounted, creating a hands-free tool. Dropping prices and federal grants are making it easier for firefighters to access these potentially lifesaving devices.



A downy killer wages chemical warfare

It may look sweet and fuzzy. But make no mistake. It's a cold, calculated murderer.

The assassin, a common fungus called *Beauveria bassiana*, slays with a vast arsenal of chemical weapons, leaving corpses in a fluffy white shroud (including the caterpillar above). And like any trained killer, it quickly moves on to the next victim. "If you've got six to eight

legs, it is going to go after you," says molecular biologist and biochemist Nemat Keyhani of the University of Florida in Gainesville. People and other vertebrates are generally safe, he says.

With a cocktail of enzymes, *B. bassiana* bores through the armor of more than 700 arthropod species worldwide. Once inside a victim, the fungus feasts on the

INTRODUCING

A yeti crab that swarms around Antarctic hydrothermal vents

A little yeti crab makes the most of a pretty rough neighborhood.

Newly discovered *Kiwa tyleri* lives in the dark about 2,500 meters below the surface of the Southern Ocean around Antarctica, researchers in England report June 24 in *PLOS ONE*.

K. tyleri's stout body and spiny legs help it cling to the walls of hydrothermal vents, where it seeks a narrow comfort zone between superheated vent water and subzero seawater. *K. tyleri* seems to thrive there: Scientists found more than 700 yeti crabs crammed into 1 square meter.

Like their mythical hirsute namesake, yeti crab species have thick, hairlike bristles. *K. tyleri*'s bristles, on its limbs and belly, might help the crab collect the bacteria that it eats. — *Sarah Schwartz*

The female of the eyeless, compact yeti crab *Kiwa tyleri* is above; the male is below.

doomed creature's bloodlike hemolymph, nimbly evading prey defenses with tricks, some unknown to science.

When the fungus is finished dining on hemolymph, usually after a few days, it simply eats its way out through the insect's tissue. To ensure that no scavenging microbes share its kill, *B. bassiana* also spews antimicrobial compounds throughout the dead body. Satiated, the fungus blooms; ivory wisps of fungal strings and tiny spores burst from the carcass' seams and with any luck, land on the next target.

The bug carnage has seized scientists' interest at least since 1835, when naturalist Agostino Bassi discovered the fungus knocking off silkworms in Italy. In the decades since, some researchers have tried to train the killer fungus to slaughter unwanted pests such as fire ants, bedbugs,



The common white fungus *Beauveria bassiana* is an insect assassin.

mosquitoes and ticks. Other scientists including Keyhani focus on learning about *B. bassiana*'s chemical warfare.

Many fungi attack insects. But *B. bassiana* has provided a rare window into insect countermeasures against assaults. Keyhani and colleagues recently revealed a common

grain-eating beetle's uncommon talent: It can shield itself from the assassin using its own antifungal compound. Although *B. bassiana* in turn has an enzyme to destroy the compound, the fungus

doesn't produce enough of it to overthrow the beetle's defense.

The finding, reported June 8 in the *Proceedings of the National Academy of Sciences*, may be a rare snapshot of an evolutionary competition between insect prey and vicious fungal killer. In this chemical arms race, the beetle is winning — for now. — Beth Mole



SCIENCE STATS

Most of Earth's impact craters await discovery

Earth's surface could hide some big blemishes. More than 90 impact craters larger than a kilometer across await discovery, researchers estimate in the Sept. 1 *Earth and Planetary Science Letters*.

While scars from meteor impacts pepper other planets — Mars alone has more than 300,000 — erosion has buffed away most of Earth's craters. Only 188 confirmed impact craters of any size dot Earth's surface, such as the Pingualuit Crater in northern Canada (shown). But more are out there. Pairing estimates of how often space debris whacks Earth and how fast erosion collapses the resulting holes, researchers calculate that about 350 craters wider than 250 meters remain undiscovered.

Crater hunters should note that accumulated sediment probably obscures many of these craters.

— Thomas Sumner

Craters found and missing

Diameter (kilometers)	Confirmed craters	Undiscovered craters
≥6	70	0
4–6	12	5
2–4	12.5	29
1–2	11	60
0.5–1	2.5	106
0.25–0.5	4	150

Earth has 188 known impact craters (including ones smaller than 0.25 kilometers in diameter). Perhaps 350 more big ones are out there awaiting discovery. Confirmed craters straddling two size ranges are counted as half for each.

SOURCE: S. HERGARTEN AND T. KENKMANN/EARTH AND PLANETARY SCIENCE LETTERS 2015



THE -EST

Brightest galaxy

Light pours out of the brightest known galaxy (illustrated).

The most luminous known galaxy blasts out as much light as roughly 350 trillion suns, researchers report.

A supermassive black hole lurking in the galaxy's core probably powers this cosmic beacon, Chao-Wei Tsai, an astronomer at NASA's Jet Propulsion Laboratory in Pasadena, Calif., and colleagues report in the June 1 *Astrophysical Journal*. They found the galaxy while scouring data from the WISE satellite, which spent about a year surveying the sky for anything glowing in infrared. The infrared light from this galaxy, dubbed W2246-0526, comes from dust heated by a blazing-hot disk of gas churning around the black hole.

The high temperatures and blankets of dust have earned this galaxy and others like it the moniker Hot DOGs, for hot dust-obscured galaxies. The light from this Hot DOG, which lurks in the constellation Aquarius, took 12.4 billion years to reach Earth. — Christopher Crockett

DNA resolves Kennewick Man debate

Ancient skeleton closely related to modern Native Americans

BY BRUCE BOWER

Native Americans can claim Kennewick Man as one of their own, an analysis of DNA from one of the ancient individual's bones finds. But the investigation's suggestion that Kennewick Man had especially close genetic ties to Native Americans who want to rebury his bones is controversial.

DNA extracted from a man's 8,500-year-old skeleton, which was found in Washington State in 1996, is more closely related to that of modern Native Americans than of populations elsewhere in the world. A team led by paleogeneticist Morten Rasmussen of the University of Copenhagen reports the findings online June 18 in *Nature*.

Kennewick Man displays the greatest genetic similarity to northern Native Americans, especially the Colville, Ojibwa and Algonquin, the scientists say.

In 2004, a federal judge denied a request by five Northwest tribes, including the Colville, to bury Kennewick Man as one of their ancestors. Intensive scientific study of the bones commenced at that point.

Part of the controversy surrounding Kennewick Man's possible connection to modern Native Americans concerns previous reports that his skull looks much like those of native Polynesians and a native Japanese group called the Ainu. Anthropologists on Rasmussen's team found the same pattern but argue that, due to large individual differences in skeletal traits within a single population, no conclusions can be drawn about Kennewick Man's heritage from one skull.

Comparisons of ancient and modern DNA stand a better chance of unraveling Kennewick Man's place in New World human evolution, the researchers say. Of the five tribes participating in the law-

suit, only two members of the Colville provided DNA to Rasmussen's group for comparison with Kennewick Man.

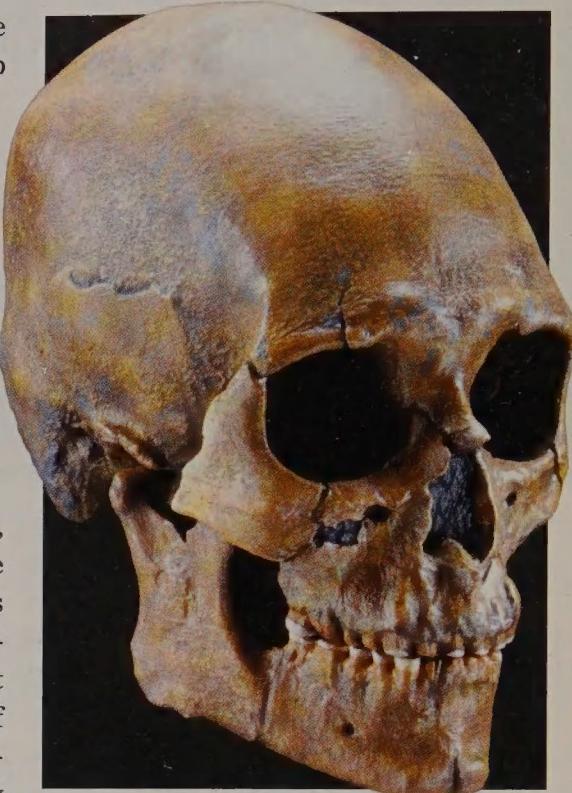
"I expect that the other four tribes are also closely related to Kennewick Man," says study coauthor Eske Willerslev, also a University of Copenhagen paleogeneticist. At this point, there's no way to tell which present-day Native American group has the closest genetic ties to the ancient American, Willerslev says.

James Chatters, the first scientist to ever study Kennewick Man's remains, says it's too early to conclude that the ancient man has particularly close links to any Native American tribe, including the Colville. Little is known about the genetics of people from most of the 566 Native American tribes registered in the United States as of January 2015, says Chatters, an archaeologist at Applied Paleoscience, a private consulting firm in Bothell, Wash. The Colville people consist of 12 confederated bands in Washington State, some descending from coastal groups and others from inland groups, he adds. DNA from two Colville individuals doesn't provide

nearly enough evidence to characterize Kennewick Man's genetic relationship to the entire Colville population today, Chatters contends.

"DNA from many more modern Native American groups needs to be sampled before any broad conclusions can be drawn from the genes of one ancient skeleton," Chatters says. Rasmussen's team can say with confidence only that Kennewick Man shared a common genetic heritage with all modern Native Americans, Chatters says.

Consistent with Kennewick Man's broader DNA connection to Native Americans, a Chatters-led study found a genetic connection between a girl whose



Kennewick Man's skull resembles those of native Polynesians, but a DNA analysis finds that the ancient skeleton discovered in Washington State shares ancestry with Native Americans.

12,000- to 13,000-year-old remains were found off Mexico's coast and today's Native Americans (*SN: 6/14/14, p. 6*).

A baby buried in Montana about 12,600 years ago also was a genetic ancestor of modern Native Americans with DNA roots in Northeast Asia (*SN: 3/22/14, p. 6*). That child shows closer genetic ties to Central and South American tribes than Kennewick Man does, Rasmussen's group found.

Rasmussen's team conducted statistical comparisons of Kennewick Man's recovered DNA with DNA from the ancient Montana infant and from 37 present-day native groups in Greenland and the Americas. DNA was available for 10 Native American populations in North America.

Genetic similarities between the Colville and Kennewick Man suggest that the ancient man's population and the Colville split from an ancestral group about 9,200 years ago, the scientists say. ■

Wrinkled brain mimics paper ball

Power law relationship for folding applies across species

BY LAURA SANDERS

Cramming a big brain into a skull may be as easy as just wadding it up. The same physical rules that dictate how a paper ball crumples also describe how brains get their wrinkles, scientists suggest in the July 3 *Science*.

That insight, arrived at in part by balling up sheets of standard-sized A4 office paper, offers a simple explanation for the ridges and valleys that give rise to thoughts, memories and emotions. The results also explain the shapes of a multitude of mammal brains ranging from the ultrawrinkled dolphin brain to the smooth brain of manatees, says study coauthor Suzana Herculano-Houzel.

Some researchers argue that the simple physical explanation ignores evidence of other factors involved, such as nerve cell production and the behavior

of genes. How the brain folds is still up for debate, they say. "It could very well be that aspects of the paper are true," says neurobiologist Wieland Huttner of the Max Planck Institute of Molecular Cell Biology and Genetics in Dresden, Germany. "But I think it is overstated to say that this is the only explanation and that it is universal."

Herculano-Houzel and Bruno Mota, both of Universidade Federal do Rio de Janeiro, examined brains from 74 mammal species.

By studying various brain properties, the team uncovered a simple mathematical relationship known as a power law. Brain wrinkledness depended on the relationship between two physical properties: surface area and thickness of the cortex, the brain's outermost layer. Brains fold more when the cortex is thin and has a large surface area. The team measured brain folding for each species by finding how much of the cortex was buried underneath its surface. The equation linking surface area and thickness predicted folding amounts, the team found.



When sheets of paper were scrunched, variations in surface area (larger at top) led to balls with different levels of folding. Surface area is one part of a new equation that may help describe how mammal brains fold.

By crumpling papers of different dimensions and stacking them to create different thicknesses, the team found that the same mathematical relationship describes how a paper ball crumples.

The new description of brain folding is unexpected in part because of what it leaves out. The number of nerve cells, or neurons, has nothing to do with brain folding, an idea that other research had suggested. "Numbers of neurons do not matter," Herculano-Houzel says.

Not everyone is convinced. "I absolutely disagree with that," Huttner says. Other studies have clearly shown that the birth of new neurons has a profound effect on brain folding, he says. Many of those studies focused on how the brain folds as it grows, and not the final folded product as in the new study. ■

Heat spurs sex reversal in wild lizards

Temperature-switched bearded dragons still breed successfully

BY SUSAN MILIUS

Some genetically male Australian bearded dragons are growing up as fully functional females in the wild — the first reptiles confirmed to reverse sex under natural conditions.

Eleven of 131 *Pogona vitticeps* lizards caught at several sites in southeastern Australia during three years had female sex organs but the male ZZ set of sex chromosomes, says Clare Holleley of the University of Canberra in Australia. This survey shows that sex reversal in reptiles isn't just a lab curiosity, Holleley and colleagues report in the July 2 *Nature*.

Earlier work had shown that genetics dominates in determining sex in bearded dragons during development at tempera-

tures below 32° Celsius. When embryos develop at higher temperatures, environment overrides genetics in some males and directs them to grow female bodies.

After discovering the feminized males, researchers paired six sex-change lizards (four wild-caught and two lab-bred) with normal genetic ZZ males. These lizards not only mated successfully but produced 47 eggs per year on average, about twice the normal number, Holleley says.

With no genetic female moms to pass on the feminizing W chromosome, the next generation inherited only Z chromosomes. If overheating wild bearded dragons follow this scenario, the W in a population could dwindle fast. And the possibility for genetic sex determination

could disappear, creating a population that relies on temperature to determine which eggs grow up male or female.

Biologists have already recognized that control of sex determination has switched back and forth between genetics and the environment over the course of lizard evolution.

What overheating means for wild lizards as the climate warms remains to be seen, says Nicola Mitchell of the University of Western Australia in Crawley. Mitchell worries that the tuatara she studies might single-sex themselves to extinction. But, she says, "there is no definitive answer yet as to whether a switch to temperature sex determination makes a species more or less vulnerable to global warming." Many ancient reptile lineages, such as sea turtles, determine sex by temperature, she says, "yet have persisted throughout eons of environmental change." ■

Far-off galaxy may hold primeval stars

UV light hints at cache of members of earliest stellar population

BY CHRISTOPHER CROCKETT

A stash of one of the earliest generations of stars might be lurking in a galaxy whose light has taken nearly 13 billion years to reach Earth. The finding may provide a rare look at how, when and where stars arose out of the pristine gas that was left behind in the wake of the Big Bang.

While other galaxies house clusters that could be typical of first-generation stars, the new observations provide the most direct evidence of such a population. Astrophysicist David Sobral of the Institute of Astrophysics and Space Sciences in Lisbon, Portugal, and colleagues describe the findings June 4 at arXiv.org in a paper that will appear in the *Astrophysical Journal*.

A galaxy called CR7 is loaded with hydrogen that is blasting out ultraviolet radiation — about three times as much as any other known galaxy from that time. The galaxy is also blazing with light from helium atoms stripped of an electron.

"We see indications of very, very hot sources," Sobral says, "hotter than any star we know of in our galaxy." To ionize helium, the surfaces of such stars must sizzle at around 100,000° Celsius. The sun, by comparison, is 5,500°.

Stars typical of the first stellar generation, known as Population III stars, are prime candidates as the source of all that energy. Researchers suspect that Popu-

lation III stars are incredibly large, possibly up to a thousand times as massive as the sun. Such stars burn hot and die young, lasting at most a few million years.

Certain types of dying stars as well as gassy disks swirling around supermassive black holes can also provide that much energy. What's special about CR7, Sobral says, is the apparent lack of heavier elements such as carbon and oxygen. Such atoms are forged in the centers of stars. The absence of these elements indicates that the gas contains only hydrogen and helium — typical of the gas out of which the first stars formed.

"It's definitely an unusual object," says astrophysicist George Becker of the Space Telescope Science Institute in Baltimore. But Population III stars aren't the only, or even the most likely, possibility, he says. Scientists think the first stars arose a few hundred million years after the Big Bang. As they die and explode, these stars quickly pollute the surrounding gas with heavier elements. To have a large burst of pristine star formation roughly 1 billion years after the Big Bang seems unusual, Becker says. By then, typical star formation should have overwhelmed the Population III nurseries.

The light could be coming from a group of stars that have trace amounts of carbon and oxygen, undetectable with current instruments. Or it could be coming from pristine gas that is cooling off from earlier bursts of star formation, Becker says.

"The observations they're making are very challenging," he says, "which is part of why they're exciting."

This galaxy offers a preview of what the James Webb Space Telescope, scheduled to launch in 2018, could see, Sobral says. Hunting for Population III stars is one of its main goals. A large mirror in space combined with instruments sensitive to infrared light will be able to tell which stars are members of the first generation and which are not. ■

Crack threatens Antarctic ice shelf

Larsen C could shed massive section within next few years

BY THOMAS SUMNER

Scientists have spotted the mortal wound that could prompt the collapse of Antarctica's fourth-largest ice shelf.

Satellite images reveal that a crack in Larsen C rapidly extended tens of kilometers across the ice shelf in 2014. If the crack reaches the ice shelf's edge, it could snap off a roughly Delaware-sized area, researchers report June 15 in *The Cryosphere*. Such a loss would reduce Larsen C's area by about 10 percent, enough to shrink the shelf to its smallest size in recorded history and potentially start the shelf's disintegration.

Lead author Daniela Jansen, a glaciologist at the Alfred Wegener Institute for Polar and Marine Research in Bremerhaven, Germany, expects that the crack will chip apart Larsen C within five years. "We should keep a close eye on Larsen C," she says. "It might not be there for so much longer."

Since Larsen C already floats in the ocean, the break-off won't immediately raise global sea levels. But if the shelf collapses — as happened to Larsen C's siblings, Larsen A and Larsen B (SN: 10/18/14, p. 9) — then glacial ice could flow into the sea unabated.

Larsen C, covering about 55,000 square kilometers, is the largest ice shelf along the Antarctic Peninsula. The shelf is fed by several mountain glaciers that flow from the continent's interior into the ocean. Relatively warm marine ice fills the gaps between the glaciers and sews the ice shelf together. These long suture zones are more malleable than the surrounding glacial ice and are less likely to crack when squeezed or pulled.

Near Larsen C's edge is the Gipps Ice Rise, a rocky bump in the landscape that blocks the flow of ice into the ocean. Ice often fractures as it moves around the ice rise, creating long cracks that run



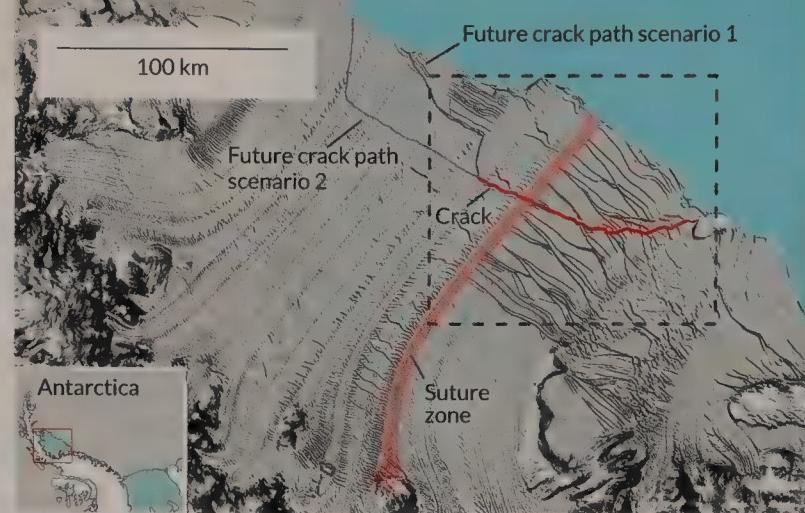
Ultraviolet light from clouds of hydrogen and helium in a distant galaxy, illustrated, suggest that primordial stars lurk inside.

perpendicular to the suture zones. The cracks extend to the bottom of the ice and grow until they hit a suture zone. Dozens of cracks neatly terminate along the suture zone near the Gipps Ice Rise.

In November 2014, Jansen assembled satellite images of Larsen C and noticed something unusual: A crack had spread past the suture zone and was more than halfway toward breaking off a large section of the ice shelf. Archived satellite images revealed that the crack grew between late 2010 and late 2012 before reaching the suture zone and stabilizing. During 2014, the crack abruptly broke through the suture zone, growing about 20 kilometers in less than nine months.

Jansen and colleagues simulated likely paths that the crack could take as it spreads toward the ice shelf's edge. In one scenario, the crack cuts off 6,400 square kilometers of ice and shrinks Larsen C by 12 percent.

Crackdown A crack in Antarctica's Larsen C ice shelf grew roughly 20 kilometers in 2014, ripping through a suture zone of soft marine ice that usually resists fracturing. Researchers simulated multiple paths that the crack could follow to the ice shelf's edge.



For now, scientists are literally in the dark about Larsen C's status. Not enough light reaches Antarctica during its winter for satellites to monitor the ice shelf. When daylight returns in August, the team will get its first look at whether the crack has spread in the last few months.

The cause of the crack's unexpected growth is unknown. But it could be related to higher ocean and air temperatures that have thinned the ice shelf, says Eugene Domack, an earth sci-

tist at the University of South Florida in St. Petersburg. If the crack growth "is somehow related to a somewhat thinner ice shelf than what we're traditionally used to," he says, "then it opens up this idea of slow thinning as a gradual lead-up to a more catastrophic decay."

A better understanding of how and why the crack expanded so quickly could help scientists better predict the future of all Antarctic ice shelves, says Richard Alley, a glaciologist at Penn State. ■

LIFE & EVOLUTION

Ivory DNA tracks elephant poaching

Two African regions ID'd as centers of illegal trafficking

BY MEGHAN ROSEN

Ivory poachers tend to hunt elephants in just a few key spots in Africa.

The DNA signatures of smuggled tusks seized by law enforcement officials over nearly 20 years finger central and southeastern Africa as hotbeds of organized ivory-trafficking crime and corruption, scientists suggest online June 18 in *Science*.

Other evidence had pointed to these areas before, but the new work "shows a smoking gun," says Fiona Maisels of the Wildlife Conservation Society in New York City. Identifying major poaching spots may help officials zero in on big ivory cartels, she says.

Illegal ivory trading has whittled the population of African elephants down to about 400,000. In recent years, poachers have killed roughly 50,000 elephants

annually. To figure out where to focus protection efforts, scientists have tried to uncover where poaching is worst.

Tracking elephant populations and carcass locations has provided some clues. And shipment data from containers of seized ivory have helped sketch a rough picture of the contraband's path out of the continent.

"So you have this idea of where a container moved and where it originated," says George Wittemyer, a conservation biologist at Colorado State University in Fort Collins, "but you don't know where the ivory itself came from."

To find out, Samuel Wasser, a conservation geneticist at the University of Washington in Seattle, and colleagues genetically analyzed ivory samples from 28 large seizures made across Africa and Asia from 1996 to 2014. The team matched the DNA signature of each sample to a reference map charting the signatures of elephants from all over Africa.

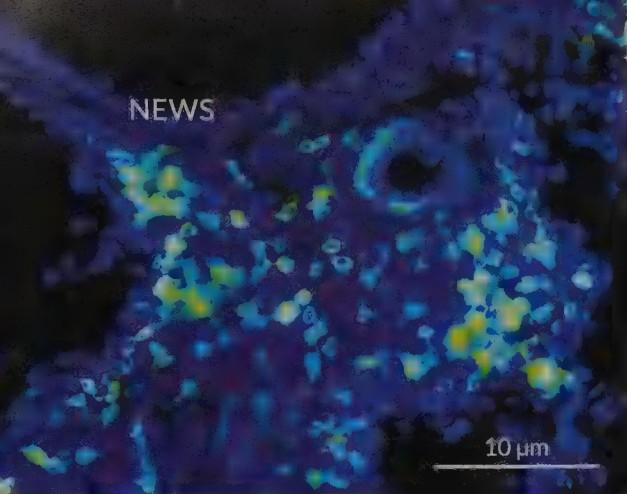
With the map, the researchers traced the origin of each piece of ivory. After 2006, the majority came from just two areas: in central Africa, a region that spans northeastern Gabon, north-

western Democratic Republic of the Congo, the southeast tip of Cameroon and the neighboring Dzanga Sangha Reserve in Central African Republic; and in southeastern Africa, a roughly 150,000-square-kilometer swath from Tanzania to northern Mozambique.

Scientists had previously pegged Tanzania as a hub for poachers. "But we didn't know how extreme it was," Wasser says. "It's just mind-blowing."

A recent census of elephants showed that Tanzania lost about 12,000 last year. Tanzanian officials have said that maybe the elephants just left the country. But the new data say otherwise: Researchers traced tons of ivory to Tanzanian elephant populations. "This kind of evidence is hard to deny," Wasser says.

The small number of poaching hot spots suggests that just a few large and powerful international crime cartels are responsible for most of the illegal ivory trade, Maisels says. Such a huge amount of trafficked ivory probably involves a vast network of corrupt officials. "You can't move hundreds of tons of illegal material without the involvement of law enforcement agencies," she says. ■



BODY & BRAIN

Turning off nerve cells eases asthma

Mice's coughing, inflammation calmed by inhaled anesthetic

BY MEGHAN ROSEN

To stop an asthma attack, just numb some nerve cells.

Dulling nerve cells in mice's lungs soothes airways by easing inflammation and out-of-control coughing, researchers report online June 25 in *Neuron*.

"It's a game changer," says asthma researcher Christopher Evans of the University of Colorado Denver. He thinks targeting nerve cells could be a feasible

Numbing pain-sensing fibers in the airways could help treat asthma. In this mouse lung, pain fibers catch a whiff of the spicy chemical in hot peppers and recruit immune cells (green), which can crank up inflammation.

therapeutic approach for asthma.

In people with asthma, pollen or dust mites can trigger wheezing. Researchers thought that response was an immune problem, Evans says. The immune system acts as a cellular bodyguard, using powerful weapons to fight dangerous microbes. But sometimes the bodyguard pulls out the big guns too soon. In asthma, the immune system overreacts to minor threats — kind of like killing a mosquito with a bazooka. The damage can include inflamed, mucus-clogged airways that make breathing difficult.

Steroids can calm the trigger-happy immune system. Another drug can force clenched airways to open. But that drug can wear off quickly, and long-term steroid use can cause infection.

Harvard University biologist Clifford Woolf and colleagues knew that pain-sensing nerve fibers line the lungs. When these fibers get a whiff of smoke or

cayenne pepper, for example, they protect the lungs by triggering a cough. People with asthma have a lot more pain fibers and they're especially sensitive.

Turning off the pain fibers could curb coughing, the researchers surmised. So Woolf's team made asthmatic mice inhale a nerve-numbing drug, called QX-314, that's related to the anesthetic lidocaine.

The drug calmed coughs, but the researchers were surprised to discover that it dialed down inflammation, too. Numb nerve cells no longer sent out messages that rile up the immune system.

"It's the first direct link I've seen between the nervous system and the immune system in asthma," says molecular biologist Kirk Druey of the National Institute of Allergy and Infectious Diseases in Bethesda, Md.

Respiratory researcher Ulaganathan Mabalirajan of the Institute of Genomics and Integrative Biology in New Delhi cautions that the drug may not work for all types of asthma. "When you have inflammation, QX-314 works fantastically," he says. But some people with asthma don't have inflammation. ■

BODY & BRAIN

Periodic near-fasting yields benefits

Curtailing calories on a schedule reduces body fat, study finds

BY TERESA SHIPLEY FELDHAUSEN

Slashing your food intake for just five consecutive days a month can yield a bounty of health benefits, researchers say. This briefer approach to caloric restriction, a severe form of dieting, challenges previous research that dieters might need to tighten their belts as often as twice a week to see effects.

The researchers fed mice and humans a "fasting-mimicking diet," a low-calorie, high-nutrition plan designed to trick cells into thinking they were fasting. The faux fasting periods lasted a few days and were followed by cycles of eating as much and as often as subjects wanted. The results appear online June 18 in *Cell Metabolism*.

Study coauthor Valter Longo of the University of Southern California says

the results show "that you can have a smart diet" without the severity seen in other caloric-restriction regimens.

Mice on the diet lived about 11 percent longer (although the diet did not extend the life span of very old mice), had fewer indicators of inflammation and cancer, and grew more nerve cells in the brain, even when old.

People on the diet had reduced amounts of C-reactive protein (an indicator of inflammation and heart disease), lost fat and gained lean muscle. The low-protein, high-fat diet — which consisted of about 1,100 calories on the first day and 725 calories a day for the next four — triggered a 3 percent loss in body weight, on average. Information about the exact foods that participants ate is proprietary.

The human trial was small — just 19 dieters — and short, lasting three months. Mice ate the diet for two four-day cycles a month for roughly half their lives.

In many studies, caloric restriction has been shown to extend life span and improve health in certain organisms. But other research has produced conflicting results, and scientists aren't sure how it works (*SN: 1/24/15, p. 6*; *SN Online: 7/30/14*).

For nerve cell growth, this study hints that the rest periods between dieting bouts, not the time spent cutting calories, is what's important, says neuroscientist Mark Mattson of the National Institute on Aging in Baltimore. In his own work, Mattson has found that fasting can yield nerve cell regeneration in the mouse brain, but his mice endured a much stricter fasting regimen of little to no food every other day. The new research shows the importance of the refeeding and recovery periods, he says. ■

More dark galaxies reveal themselves

Hundreds of nearly starless suspects found in nearby cluster

BY CHRISTOPHER CROCKETT

Hundreds of shady characters are lurking in a nearby neighborhood of galaxies. The Coma cluster houses nearly 20 times as many dark galaxies as previously known, researchers report. These shadowy figures — some as large as the Milky Way but with just one-thousandth the number of stars — could be dead ends in galactic evolution.

The cluster houses at least 854 of these barely perceptible galaxies, and there could be well over 1,000. These “ultra-diffuse galaxies” appear to have had much of their star-forming gas stolen, Jin Koda, an astronomer at Stony Brook University in New York, and colleagues report. The findings appear online June 24 in *Astrophysical Journal Letters*.

Last year, another team found 47 ultra-diffuse galaxies in the Coma cluster (*SN: 12/13/14, p. 9*), a bevy of thousands of galaxies that sits roughly 330 million light-years away in the constellation Coma Berenices. Koda and colleagues wondered if a bigger telescope could find even more dark galaxies, so they dug through images of the cluster taken by the 8-meter-wide Subaru Telescope in Hawaii.

“It’s a beautiful result,” says Yale astronomer Pieter van Dokkum, who led the discovery of the first 47 dark galaxies.

These galaxies are relics from an earlier time. They haven’t formed any stars in the last 4 billion to 10 billion years, Koda says. The galaxies aren’t scattered around the cluster haphazardly, as would be expected if they were new arrivals falling into Coma randomly. They are instead arranged symmetrically around the heart of the cluster, indicating that they have been lurking within Coma for a long time.

Their longevity is surprising. Star-starved galaxies are gravitationally tugged to and fro by their brighter, more massive brethren. With so few stars, the dark galaxies should have been torn apart

long ago. “For these fluffy-looking galaxies to survive, they need something like dark matter protecting them,” Koda says.

All galaxies are held together by dark matter, elusive particles that neither emit nor absorb light, revealing themselves only by their gravitational influence. These murky galaxies, however, take it to an extreme. To survive the rough-and-tumble streets of Coma, the dark galaxies must be over 99 percent dark matter — a far cry from the roughly 85 percent that’s typical of galaxies.

“These things were not expected to be there,” van Dokkum says. They could



Eight dark galaxies (circled) are among more than 800 in the Coma cluster (shown). Those circled in green are newly discovered.

be failed galaxies, he says. Something might have stripped them of their gas, leaving behind a smattering of stars and a massive storehouse of dark matter.

One way to sweep out the gas, Koda says, is with a wave of supernova explosions. If enough stars exploded fast enough, maybe they could have launched all of the spare gas out of the galaxy. ■

ATOM & COSMOS

No plate tectonics on super-Earths

Large rocky planets have stiff outer shells, study suggests

BY THOMAS SUMNER

Plate tectonics may not rumple the surfaces of Earth’s supersized cousins.

Simulating the pressures inside giant exoplanets called super-Earths, scientists discovered that these planets probably have thick, stagnant outer shells and sluggish internal circulation. Those properties make the existence of fragmented jigsaw puzzles of sliding and shifting surface sections unlikely, the team reports in a paper to be published in the *Journal of Geophysical Research: Planets*.

Plate tectonics drives Earth’s carbon cycle, which helps regulate the planet’s temperature and allows life to flourish, says study coauthor Takehiro Miyagoshi, an earth and planetary scientist at the Japan Agency for Marine-Earth Science and Technology in Yokohama.

“We think super-Earths are boring,” he says. “This point should be kept in mind in our search of habitable planets.”

Earth’s tectonic plates are driven by

a conveyor belt of sinking and rising rock. Previous studies predicted that the extra heat insulated inside super-Earths would easily power similar convection.

Those studies repurposed simulations of Earth’s internal movements without considering changes that come with a bigger planet, Miyagoshi says. Larger planets put more pressure on their interiors, boosting temperatures at lower depths.

Miyagoshi and colleagues simulated a planet with 10 times Earth’s mass. As cold rock blobs descended into the simulated super-Earth’s interior, rising pressures heated the rock and stalled its fall. Climbing magma plumes decompressed as they rose toward the surface, lowering their temperature and buoyancy. This lethargic movement created a stagnant shell around the planet some 1,800 kilometers thick, about the radius of the moon.

This work isn’t the final word, says geodynamicist Brad Foley of the Carnegie Institution for Science in Washington, D.C. Scientists don’t fully understand why Earth has plate tectonics while other planets, such as Venus, don’t, he says. “Until we know that well, we’ll always be all over the place when we try to predict what will happen on super-Earths.” ■

Music to just about everyone's ears

Statistical analysis finds globally shared rhythms, pitch changes

BY BRUCE BOWER

Roll over Beethoven and tell Tchaikovsky the news: Scientists have for the first time identified key characteristics of music worldwide. The findings lay the groundwork for deciphering why people everywhere sing, play instruments and find melodies so compelling.

No musical features, not even simple scales composed of distinct pitches, are absolute universals that occur in all song traditions, say Patrick Savage, an ethnomusicologist at Tokyo University of the Arts, and his colleagues. However, 18 features are statistical universals: They occur in a large majority of musical cultures, the researchers report online June 29 in the *Proceedings of the National Academy of Sciences*.

Ten of those features commonly occur together and revolve around group performance and dancing. Music everywhere tends to be simple and repetitive, the investigators find. Singing is typically accompanied by playing musical instruments, drumming and dancing.

That's consistent with a long-standing idea that music took hold in human cultures because of its ability to bind people into groups and to coordinate collective activities. "If you want to understand how music evolved, a party with music

and dancing is a much better model than a Chopin piano prelude recital," Savage says.

It's also possible that music evolved as a way for men to advertise attractive qualities to potential mates, the researchers say. In the study's global sample, males perform most instrumental and vocal music. Restrictions on females performing music in male-dominated cultures may explain that pattern, Savage says. It's unclear whether males also performed more of the music in ancient human societies, he adds.

Researchers have long debated whether any musical features are universal or any one definition of music applies to all cultures. Savage's team is the first to account for historical relationships among various musical cultures by referring to previous calculations of evolutionary links among languages spoken in those cultures (*SN: 11/19/11, p. 22*), says cognitive neuroscientist Aniruddh Patel of Tufts University in Medford, Mass. Developed by other researchers, the linguistic method compares speech sounds, grammatical rules and other elements of talk.

Relationships identified using the linguistic evidence largely matched those found in a comparison of

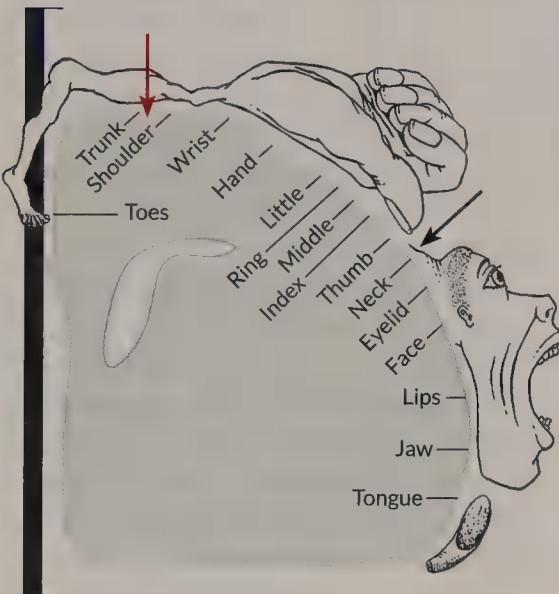
worldwide musical styles conducted by the researchers.

Savage and his colleagues searched for 32 musical features — from singing one syllable per musical note to dancing along with musical performances — in a previously collected sample of 201 recordings of native music from nine parts of the world. These regions included parts of Africa, the Americas, Asia, the Middle East, Europe and Oceania. Statistically universal features were defined as those that appeared in substantially more than half of the global sample of recordings and in at least half of the sample for each region.

These widely shared features included pitches organized in simple scales, melodies with descending pitches or pitches that rise before falling, and two- or three-beat rhythms. They also included singing from the chest, as opposed to singing extremely low or in a falsetto.

Contrary to what many researchers expected, pentatonic, or five-note, musical scales — the foundation of Western music — were not universal.

The list of statistically universal musical features "gives researchers specific targets for cross-species investigations to study how ancient and widespread the biological foundations of music really are," Patel says. Previous work has examined humanlike aspects of birdsong (*SN: 4/15/00, p. 252*), parrots' ability to move to musical beats (*SN: 5/23/09, p. 8*) and rhythmic drumming by chimpanzees. ■



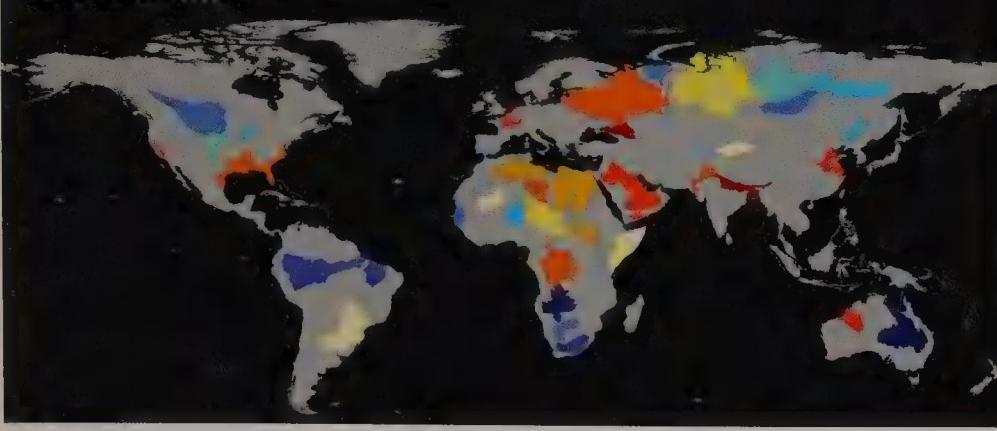
BODY & BRAIN

Homunculus reimagined

The motor homunculus is a funny-looking fellow with a big thumb, delicate toes and a tongue that wags below his head. His body parts and proportions stem from decades-old experiments that mapped brain areas to the body parts they control.

Now, a new study says that the motor homunculus's neck was in the wrong place.

Hyder Jinnah of Emory University and colleagues used functional MRI to scan the brains of volunteers as they activated their head-turning neck muscles by pushing against pads. Neck muscle firing was accompanied by activity in part of the brain that controls movement. The exact spot seems to be between the brain areas that control the shoulder and the trunk (red arrow) — not between the areas responsible for moving the thumb and the top of the head (black arrow) as earlier motor homunculi had suggested, the team reports in the June 17 *Journal of Neuroscience*. — Laura Sanders



EARTH & ENVIRONMENT

Many groundwater basins run deficits

Climate and human consumption are parching Earth's groundwater basins at an alarming rate, a new study finds. Of Earth's 37 biggest groundwater basins, 21 now lose more water annually than they take in (redder regions on map have net groundwater losses; bluer regions have net gains). Researchers report the findings in a paper to be published in *Water Resources Research*.

That's troubling, says Sasha Richey, a hydrologist now at Washington State University in Pullman. Groundwater quenches the thirst of about 2 billion people, provides irrigation for crops and helps keep some wetlands wet. "People need to think about groundwater as an important resource," Richey says. "We're not managing that resource adequately, or even at all, in most of the world."

Richey and colleagues analyzed data collected by GRACE, twin NASA satellites that measure small changes in Earth's gravity. As water pools underground, the satellites record a stronger gravitational tug. The team examined gravity changes measured from Earth's largest aquifers from 2003 through 2013. Eight of these aquifers lost significant water over the decade and were classified as overstressed, with nearly no natural water replenishment to offset withdrawals. The regions of greatest concern were the Arabian Aquifer System in the Middle East, the Murzuk-Djado Basin in northern Africa and the Indus Basin in northwestern India and Pakistan.

The most dried-up aquifers commonly had large populations nearby, substantial local agriculture and/or an arid climate. — Thomas Sumner

GENES & CELLS

How vitamin B12 makes pimples pop up

Vitamin B12 causes normal skin bacteria to produce pimple-promoting chemicals.

Both people with clear skin and those with acne have *Propionibacterium acnes* on their skin. But bacteria from acne sufferers have a different metabolism, researchers report in the June 24 *Science Translational Medicine*. Microbes from zit-ridden skin have 109 genes that are more active than normal and 27 that are less active. Taking vitamin B12 can cause similar changes in these bacteria, the researchers found.

Vitamin B12, which is important for making red blood cells and for brain function, has long been known to cause acne in some people, but researchers didn't understand why. Dezhi Kang of UCLA and colleagues gave vitamin B12 supplements to 10 people with clear skin. One developed acne a week later.

Bacteria from the vitamin takers stopped producing as much vitamin B12 because the microbes got it from their hosts. In the person who got acne, the drop in vitamin B12 production shifted the bacteria's metabolism, causing them to make chemical precursors of porphyrins. Porphyrins cause skin inflammation, leading to pimples.

The research could lead to new acne treatments that alter the metabolism of friendly bacteria in healthy ways. — Tina Hesman Saey

ATOM & COSMOS

Evidence mounts for active volcanoes on Venus

Volcanoes might be exploding on Venus, researchers report online June 17 in *Geophysical Research Letters*. The Venus Express spacecraft, which orbited Venus from 2006 to earlier this year, detected flashes of infrared light, possibly from hot lava, coming from the planet's surface. The bursts align with a rift zone, similar to cracks around volcanoes on Earth.

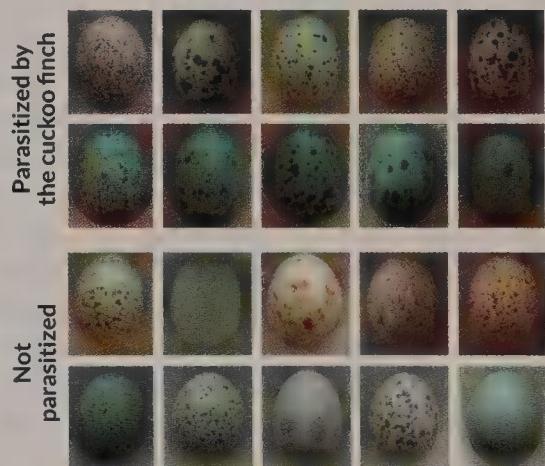
Earlier sulfur dioxide spikes in Venus' atmosphere hinted at modern-day volcanism on our neighboring planet. If lava is erupting on the surface, Venus joins Earth and Jupiter's moon Io on the list of known volcanically active worlds in the solar system. — Christopher Crockett

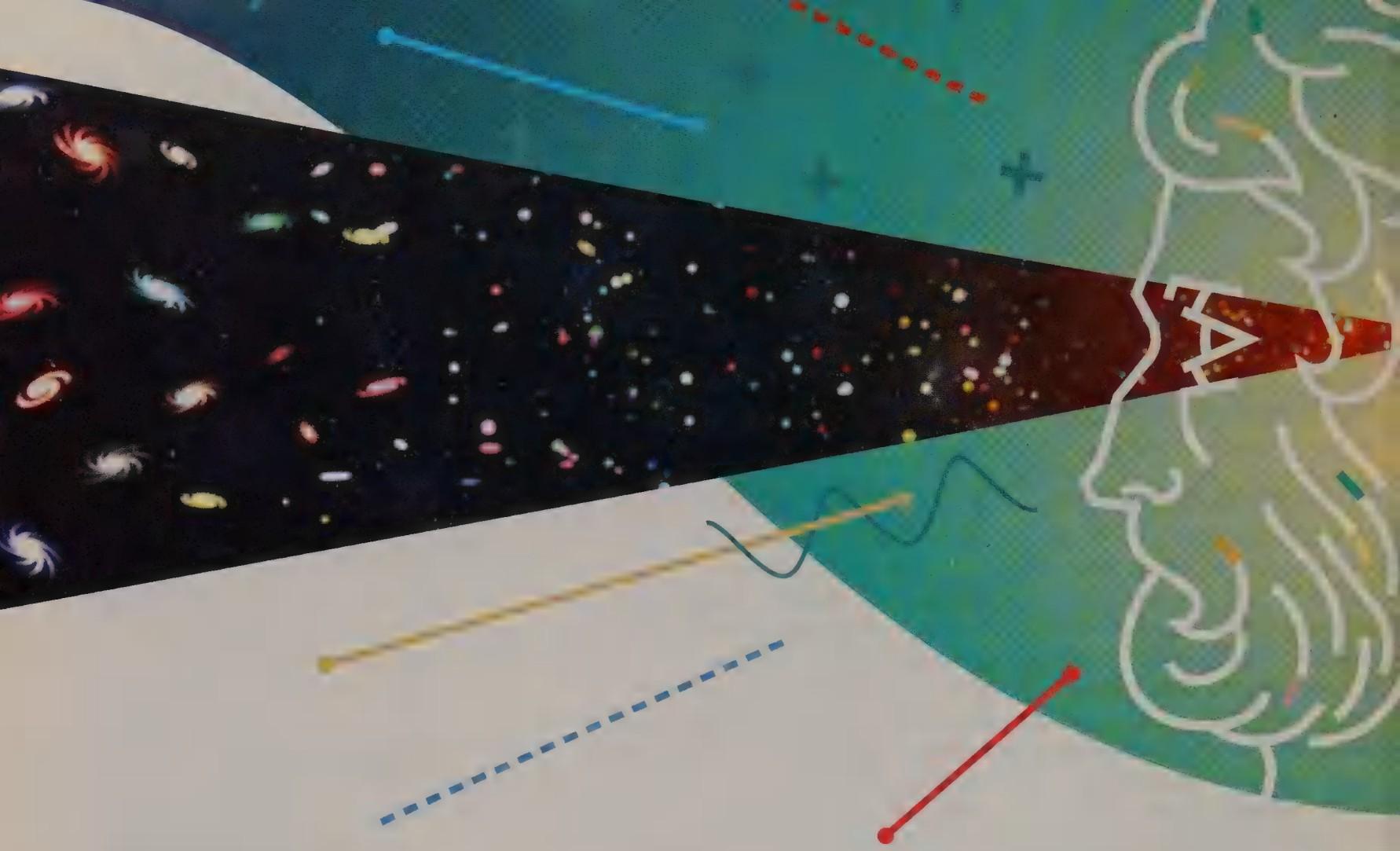
LIFE & EVOLUTION

Unpredictable egg scramble throws off parasitic parents

Some birds shirk their parental duties by slipping their eggs into other birds' nests. But the birds that host the shysters' eggs have a trick of their own — scrambling the looks of their eggs so they have distinct signatures.

Warbler species whose nests are infiltrated by the cuckoo finch and weaver species whose nests are invaded by the diederik cuckoo lay eggs with colors and markings that are individualistic and hard to mimic (warbler eggs, top two rows). Researchers report the finding in the July 7 *Proceedings of the Royal Society B*. Eggs of warbler (bottom two rows) and weaver species whose nests don't get infiltrated don't have the same degree of unpredictable patterns, suggesting that defenses against parasitic parents have evolved in the host species. — Ashley Yeager





Special Report: Dimensions of Time

Time, as the late physicist John Archibald Wheeler liked to say, is nature's way of keeping everything from happening all at once.

But time also has many other jobs. It keeps eggs from unscrambling, glass from unbreaking, and somehow accommodates the expansion of the universe. Time helps humans and other organisms function on a recurring daily schedule that alternates light with darkness. Time in the brain underlies synchronization of sights and sounds needed to make sense of the external world.

In its relationship to these tasks, time poses tough questions. Nobody really knows why time marches always forward, as the universe grows bigger and irreversible processes within it generate increasing disorder. The second law of thermodynamics is somehow involved, most physicists believe. But they can't agree on how time's direction was determined at the origin of cosmic history.

Biologists ponder time from the perspective of evolutionary history, wondering why and how life-forms acquired the internal clocks that guide daily life. Circadian rhythms associated with sleeping, waking, eating and the ebb and flow of bodily chemicals reflect a fundamental role for time in the way that living things relate to their environments. Researchers are pursuing multiple investigations into the origins of these biological clocks and how they influence life today.

Biological clockwork is especially important in the brain, where keeping track of time is essential for survival. The human brain possesses a posse of precision timekeepers tasked with keeping track of time on different scales and for different sensory purposes. Understanding the interplay of these neural timepieces is at the frontier of scientists' efforts to explain time's role in the life of the mind.

In the pages that follow are accounts of the latest scientific investigations into time's place in the physical, biological and mental worlds — timely science, aspiring to solve eternal mysteries. — Tom Siegfried

Time's Arrow

15

Gravity may explain how time always runs forward, even though the laws of physics should permit it to run backward.

Clocks Over Time

19

Humans have created timepieces over the millennia to organize daily life, guide ship navigation and now keep the world's 7 billion people in sync.

Clocking In

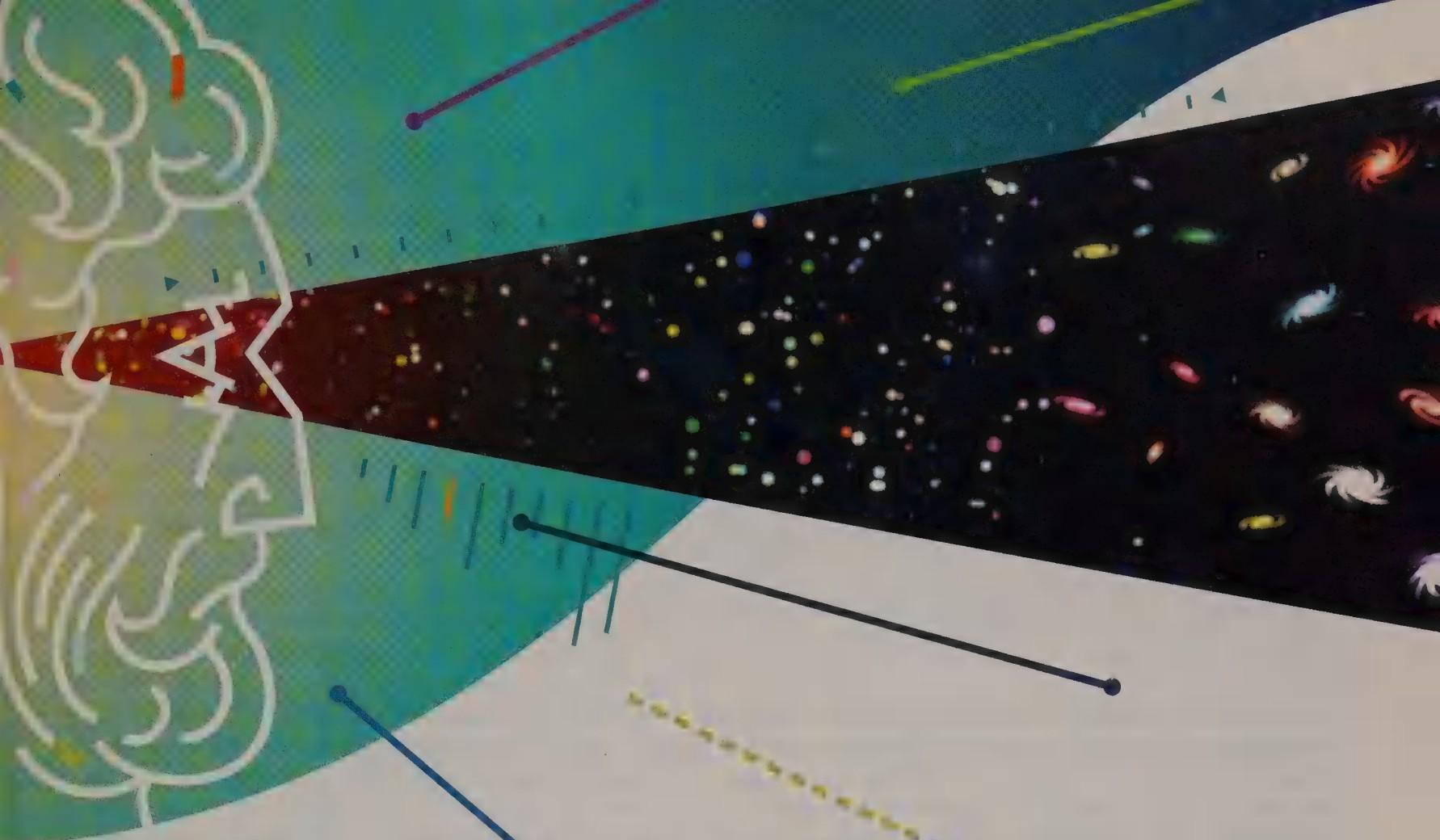
20

To perceive time, the brain relies on a diverse collection of internal clocks that precisely orchestrate movement, sensing, memories and learning.

Life's Cycles

24

Creatures large and very small keep time with the planet's day/night cycle. Scientists are still debating how and why the circadian clocks that govern biological timekeeping evolved.



TIME'S ARROW

Maybe gravity shapes the universe
into two opposing futures **By Andrew Grant**

In T.H. White's fantasy novel *The Once and Future King*, Merlyn the magician suffers from a rare and incurable condition: He experiences time in reverse. He knows what will happen, he laments, but not what has happened. "I have to live backwards from in front, while surrounded by a lot of people living forwards from behind," he explains to a justifiably confused companion.

While Merlyn is fictional, the backward flow of time should not be. As the society of ants in White's novel proclaimed, "everything not forbidden is compulsory," and the laws of physics do not forbid time to run backward. Equations that determine the acceleration of a rocket or the momentum of a billiard ball all work just as well with time flowing backward as forward. Yet unlike Merlyn, we remember the past but not the

future. We get older but never younger. There is a distinct arrow of time pointing in one direction.

For nearly 140 years, scientists have tried to rule out the backward flow of time by way

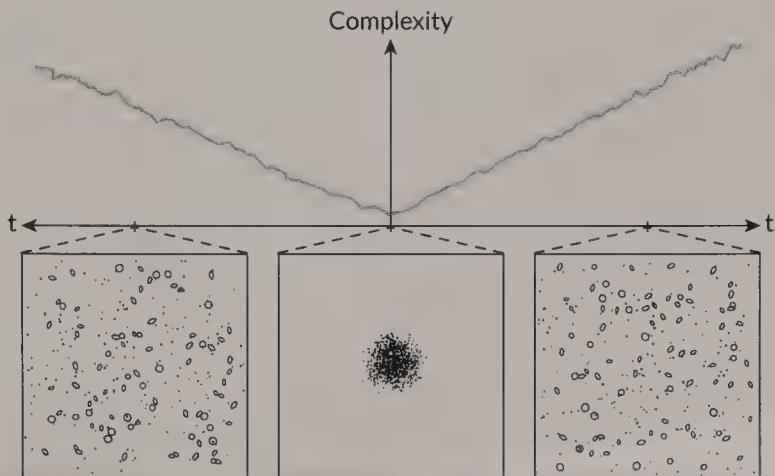
of nature's preference for disorder. Left alone, nature transforms the neat into the messy, a one-way progression that many physicists have used to define time's direction. But if nature prefers disorder now, it always has. The challenge is figuring out why the universe started out so orderly—thereby allowing disorder to grow and time to march forward—when the early universe should have been messy. Despite many proposals, physicists have not been able to agree on a satisfying explanation.

A new paper offers a solution. The secret ingredient, the authors say, is gravity. Using a simple simulation of gravitationally interacting particles, the researchers show that an orderly universe should always arise naturally at one point in time. From there, the universe branches in opposing temporal directions. Within each branch, time flows toward increasing disorder, essentially creating two futures that share one past. "It's the only clear, simple idea that's been put forward to explain the basis of the arrow of time," says physicist Julian Barbour, a coauthor of the study published last October in *Physical Review Letters*.

It may be clear and simple, but it's far from being the only

Looking to the future(s)

In this illustration, the dual faces of the Roman god Janus gaze at the universe in opposing directions of time. A new simulation suggests that the universe has one past (the Big Bang) and two futures.

Two-way time

Back and forth In a simulated universe, gravity packs particles together (middle). The particles later disperse and clump (left and right). The graph shows complexity rising in both cases, creating opposing arrows of time (t).

idea attempting to explain the mystery of time's arrow. Many scientists (and philosophers) over the decades have proposed ideas for reconciling nature's time-reversible laws with time's irreversible flow. Barbour and colleagues admit that the arrow of time issue is far from settled — there's no guarantee that their simple simulation captures all the complexities of the universe we know. But their study offers an unusually elegant mechanism for explaining time's arrow, along with some tantalizing implications. Attacking the arrow-of-time mystery along the lines Barbour and colleagues suggest may reveal that the universe is eternal.

Mixing marbles

Nobody knows exactly why time doesn't flow backward. But most scientists have suspected that the explanation depends on the second law of thermodynamics, which describes nature's fondness for messiness. Consider a jar containing 100 numbered marbles, 50 of them red and 50 blue. Someone with way too much free time then takes a picture of every possible arrangement of the marbles (yes, this would take far longer than a human lifetime) and creates a giant collage. Even though every photo depicts a different arrangement of numbered marbles, the vast majority of images would look very similar: a jumble of red and blue. Very few photos would have all the red marbles on one side of the jar and all the blue on the other. A photo picked at random would be far more likely to show a state of disorder than one of order.

Physicists in the 19th century recognized this propensity for disorder by thinking about the flow of heat in steam engines. When two containers of gas are exposed to each other, the faster-moving molecules of the higher-temperature container (think the blue marbles) tend to mix with the slower molecules (red marbles) of the cooler container. Eventually the combined contents of the containers will settle at an equilibrium temperature because a disordered state of blended hot and cold is most likely.

In the mid-19th century, physicists introduced the notion of entropy to quantify the disorder of a heat-shifting system. Austrian physicist Ludwig Boltzmann sharpened the definition by relating entropy to the number of ways that one could arrange microscopic components to produce an indistinguishable macroscopic state. The jar with segregated red and blue marbles, for example, has low entropy because only a few arrangements of the numbered marbles could produce that color pattern. Similarly, there are many combinations of speedy and sluggish molecules that will produce a gas at equilibrium temperature, the highest possible entropy. The fact that there are far more ways to achieve high entropy than low provides the foundation for the second law of thermodynamics: The entropy of a closed system tends to increase until reaching equilibrium, the maximum state of disorder.

The second law explains why cream easily mixes into coffee but doesn't unmix, and why Humpty Dumpty won't spontaneously reassemble after his fateful fall. Crucially, the second law also defines a thermodynamic arrow of time. The drive toward maximum entropy is an irreversible process in a universe governed by time-reversible physical laws. The second law suggests that time flows from past to present to future because the universe is progressing from an ordered low-entropy state to a disordered high-entropy one.

Unfortunately, physicists had to make a major assumption to connect entropy and the arrow of time. If entropy has been increasing since the Big Bang, 13.8 billion years ago, then the universe's original entropy must have been low enough that even today the universe is not close to equilibrium. Yet as the jar of marbles reveals, there are not many ways for entropy to be low. If you randomly picked the universe's initial entropy value out of a hat, "you'd almost certainly pick equilibrium," says Anthony Aguirre, a cosmologist at the University of California, Santa Cruz. A universe in equilibrium would be like the thoroughly mixed container of gas molecules: unchanging, with no heat flowing, no eggs to break, no pockets of order remaining to transform into disorder. And that's not what scientists see when they look at the universe, both in the past and today.

This early-universe entropy dilemma bothers many physicists. They want to prove that the universe is typical, that it did not need an exceptionally lucky break to evolve into its current condition. But framing the Big Bang era in terms of entropy is a slippery proposition. Back then, matter and energy were confined to a hot, dense ball. Some physicists consider that to be an orderly, low-entropy state; others say it resembles a packed container of gas molecules in equilibrium. Most physicists agree that the second law of thermodynamics is vital for explaining time's arrow, but they still want to develop a simple theory that explains the flow of time.

The Janus point

Barbour is in this camp of time thinkers. Like a random low-entropy state, he is a rarity in physics: a freelancer. After

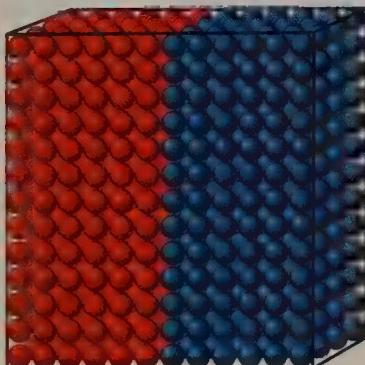
completing his Ph.D. in 1968 at the University of Cologne in Germany, he quit academia so that he could focus on fundamental physics rather than obtaining tenure. He lives in a small English parish (population 285) where the rural charm and centuries-old houses create the illusion that time has slowed since the Age of Enlightenment.

Barbour's dive into the arrow-of-time question began several years ago. He was thinking about the n-body problem, which requires determining the motion of multiple objects that are tugging on each other due to gravity. He wondered whether gravity, which clearly influences the movement of matter, could also impact the movement of time. Barbour worked on the problem with Tim Koslowski of the University of New Brunswick in Fredericton, Canada, and Flavio Mercati of the Perimeter Institute for Theoretical Physics in Waterloo, Canada. They set up a toy universe — a simple simulation used to examine the workings of the complex cosmos without all the messy details. This universe consisted of 1,000 particles in limitless space that interacted solely through Newtonian gravity.

Barbour, Koslowski and Mercati did not just toss in some particles and press play. Assuming a forward flow of time would have defeated the purpose of the exercise. Instead, they let the simulation rip and recorded a series of snapshots, like frames in a movie. Each frame captured the positions of the particles and recorded the system's complexity — a measure that quantified the spread and clustering of the particles. (For the most part, complexity increases along with entropy.) Then the researchers pieced together the frames to create a coherent motion picture, much like someone ordering stills from a video that captures the motion of a swinging pendulum.

After running the simulation many times with varying numbers of particles, Barbour and colleagues noticed an unmistakable pattern. At some instant during each simulation, all the particles would clump together into a homogeneous ball, a moment of minimum complexity. Then the complexity would increase. As the elapsed time from the instant of minimum complexity increased in either direction of time,

Nature favors disorder Marbles arranged by color (left) depict an ordered, low-entropy state. But of all possible arrangements of the marbles, the most likely are messy, high-entropy states (right).



so did the number of clumps and the distances between them.

Barbour and his team immediately made a connection to our universe and its arrow of time. At a single instant, the toy universe's 1,000 particles had formed a packed, uniform ball, which resembles the conditions at the Big Bang. From there the ball had expanded into a sparse, clumpy arrangement that is more reminiscent of today's galaxy cluster-dotted cosmos. This expansion, the shift from simplicity to complexity, occurred in both directions of time. That means that all the matter and energy that have evolved to create the cosmos we see today could also be evolving independently in the other direction of time. What we know as the universe could actually be just one of a pair that exists in the same space but at different times.

The researchers concluded that an observer living in either universe would perceive time as flowing in the direction of increasing complexity,

from the Big Bang-esque blob to the present. The arrow of time for an observer on one side of the timeline would appear to run backward from the perspective of an observer on the other side, but that would be academic: An observer could never compare notes with his or her counterpart because that would require burrowing backward through time.

Crucially, the researchers' proposal demonstrates what Boltzmann could not nearly 140 years ago: that asymmetry in time can arise naturally from time-symmetric physical laws. In fact, Barbour and colleagues proved mathematically that if the real universe behaves like the toy one, then a gravity-driven arrow of time must have arisen. This inevitability could solve the problem of why entropy in the early universe was so low. Barbour and colleagues say that the Big Bang could represent the one minimum-complexity moment in time that always arises when gravity is at work. The researchers named this pivotal instant the Janus point, after the Roman god of beginnings, who has one face looking toward the past and another toward the future.

"The proof that they give is nice and elegant," Aguirre says. But he warns that Barbour has a long way to go to prove that his simulation, which simplifies gravity and ignores quantum physics, can approximate the actual universe. Barbour says his team is working to confirm that particles would behave similarly in a universe governed by general relativity, Einstein's all-encompassing theory of gravity.

Everlasting universe

If Barbour's proposal holds up, it will offer intriguing evidence that the universe is eternal, with no beginning and no end of time. Today, many cosmologists consider the Big Bang as the start of the universe's forward-pointing arrow of time. But Barbour's simulation suggests the Big Bang serves as the starting point of two arrows that both point toward increasing disorder. The universe we know, which is guided by one of the arrows, has evolved to enable the development of stars,

"The general struggle for existence of animate beings is not a struggle for raw materials ... nor for energy ... but a struggle for entropy, which becomes available through the transition of energy from the hot sun to the cold Earth."

LUDWIG BOLTZMANN



galaxies and life; the universe on the other side of the Janus point, undetectable to us but made of the same starting ingredients, may be very similar.

In some ways, Barbour's proposal is much like one made in 2004 by cosmologists Sean Carroll and Jennifer Chen when they were at the University of Chicago. They also envisioned an eternal universe, though it existed in an equilibrium state. The catch was that occasional quantum fluctuations could spark the birth of low-entropy universes that break away, expand and evolve toward higher entropy (*SN: 6/19/10, p. 26*). Baby universes could pinch off in either temporal direction, ensuring a local arrow of time while preserving an overall time symmetry.

Aguirre, who described an eternal multiverse with local arrows of time in 2003, says these recent studies should give cosmologists pause when they consider whether the Big Bang truly marked the beginning of time. The idea of a universe with a beginning "has become so entrenched that many cosmologists seem unwilling to entertain the notion of an eternal universe," he says. While he doesn't expect that his work or that of Carroll, Chen or Barbour will sway his colleagues, he says that future astronomical observations might support the case for an eternal multiverse (*SN: 6/7/08, p. 23*).

Barbour's findings also open up a possibility that would get Boltzmann rolling in his grave. If gravity is the crucial ingredient that explains why time flows forward, Barbour says, then perhaps a new measure that incorporates gravity should replace the steam engine-inspired concept of entropy. Barbour is not arguing that entropy is useless or that the second law is wrong, but he questions whether entropy can be usefully applied to describe the universe as a whole.

Lawrence Schulman, a physicist at Clarkson University in Potsdam, N.Y., shares Barbour's entropy trepidation. "It's very hard to define entropy for the entire universe," says Schulman, who suggested in 1999 that time could run backward in some regions of the cosmos. A box of gas molecules has boundaries, he says, making it easy to describe the entire large-scale configuration of the gas; the universe stretches beyond the

billions of light-years in all directions that are visible to us. And gravity plays a far greater role in the evolution of the universe than it does in a small container of lightweight gas molecules.

As a replacement for entropy, Barbour, Koslowski and Mercati, in an upcoming paper, suggest a metric called "entaxy." From the Greek for "toward order," entaxy measures the degree of order created by gravity. It is essentially the opposite of entropy. Based on their simulation, maximum entaxy occurs at the Janus point, when gravity pulls matter and energy together into one orderly clump. As the universe evolves in both directions from that orderly point, entaxy

decreases as matter spreads apart and forms ever-smaller clumps. The entaxy of the universe has been decreasing ever since the Big Bang, Barbour says.

Carroll, who is now at Caltech and wrote a 2010 book on the arrow of time, remains staunchly on Team Boltzmann. Gravity is essential for understanding what an increasing-entropy universe looks like, he says, but that doesn't mean that gravity should be integrated into the measurement of the universe's disorder. "You know entropy when you see it," he says, even if the universe presents more challenges than a steam engine or a jar of marbles.

Carroll praises the work of Barbour and colleagues, but he thinks similar simulations would work just as well if the particles exerted no gravitational influence on each other. He is working with MIT cosmologist Alan Guth to create a simulation without gravity. Barbour's toy universe is simple but "specific," Carroll says. "We want our model to be simple and generic. We literally have no forces or interactions." The particles move in a straight line and bounce off each other like billiard balls. While Carroll and Guth have yet to produce a paper, Carroll says their toy universe also results in a Janus-like point with diverging arrows of time toward increasing entropy.

Guth and Carroll may indeed demonstrate that arrows of time can emerge without gravity's involvement. Alternatively, Barbour and his team may devise a more complete theory that incorporates general relativity and entaxy. Or maybe these simulations have nothing to say about time's arrow in the actual universe. Regardless of where the research leads, Barbour says he takes satisfaction in the simplicity of the approaches. It would be fitting, he says, if observing the behavior of a simple set of particles, which provided the first vital clue toward understanding the arrow of time, ends up finally resolving the problem once and for all. ■

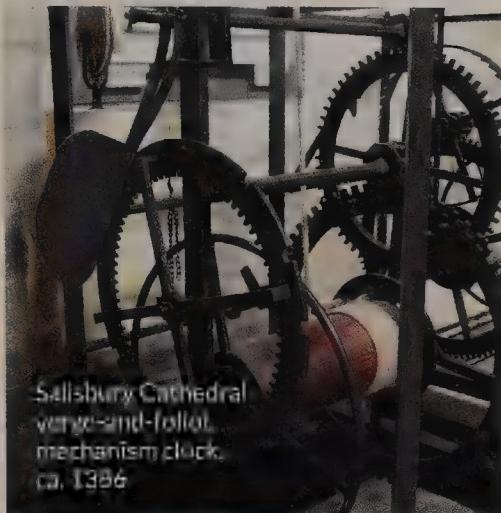
Explore more

- Julian Barbour, Tim Koslowski and Flavio Mercati. "Identification of a gravitational arrow of time." *Physical Review Letters*. October 31, 2014.

CLOCKS Over time



Egyptian sundial,
ca. 1300 B.C.



Salisbury Cathedral
verge-and-foliot
mechanism clock,
ca. 1386



Strontium optical
lattice atomic
clock, 2015

For millennia, humans have harnessed the power of clocks to schedule prayers, guide ocean voyages and, lately, to chart the universe. Whatever their use, all clocks need two basic components: a constant repetitive action (like a pendulum's swing or an atom's vibrations) and a way to mark time's progression.

—Teresa Shipley Feldhausen

1500 B.C.

SUNDIAL (EGYPT)

Shaped as tall pillars or portable and flat, sundials divided days into equal parts. Sundials were still widely used even after A.D. 1500.

1400–1300 B.C.

WATER CLOCK (EGYPT)

Water clocks, or clepsydras, let water drip out of (or into) a vessel at a nearly constant rate. Markings on inner surfaces measured the passage of time. Later versions evolved in Greece and China.

600 B.C.

MERKHET (EGYPT)

The oldest known astronomical tool established a north-south line (or meridian) by aligning two merkhet with the North Star. It marked off nighttime hours by determining when other stars crossed the meridian.

A.D. 960–1250

INCENSE CLOCK (CHINA)

Some incense clocks burned different colors or smells to mark the passage of time. Others burned threads attached to weights, eventually causing the weight to drop onto a gong below, sounding an alarm.

1300

VERGE-AND-FOLIOT MECHANISM (EUROPE)

These mechanical clocks, which first appeared in towers, used weights to convert rotational motion into oscillating motion. The rate was difficult to regulate.

1656

PENDULUM CLOCK (THE NETHERLANDS)

Dutch scientist Christiaan Huygens' clock was regulated by a pendulum's period of oscillation. His clock was accurate to within 10 seconds a day.

1735

MARINE CHRONOMETER (ENGLAND)

Self-taught clockmaker John Harrison built a chronometer that could determine longitude aboard a ship. His 1764 version kept time to about one-fifth of a second per day.

1920s

QUARTZ CLOCK

Using the electrical properties of quartz crystals, these clocks improved timekeeping performance and are still popular in watches.

1949

ATOMIC CLOCK

The first atomic clock measured time based on vibrations within ammonia, and later cesium, atoms.

1999

CESIUM CLOCK

The National Institute of Standards and Technology's cesium clock would lose just one second in 20 million years.

2015

OPTICAL LATTICE CLOCK

The most precise atomic clock yet, using strontium atoms, keeps time accurately to within a second per 15 billion years (SN: 5/16/15, p. 16).



CLOCKING IN

The brain has a throng of timekeepers that stitch together a coherent reality

By Laura Sanders

Everybody knows people who seem to bumble through life with no sense of time — they dither for hours on a “quick” e-mail or expect an hour’s drive to take 20 minutes. These people are always late. But even for them, such minor lapses in timing are actually exceptions. We notice these flaws precisely because they’re out of the ordinary.

Humans, like other animals, are quite good at keeping track of passing time. This talent does more than keep office meetings running smoothly. Almost everything our bodies and brains do requires precision clockwork — down to milliseconds. Without a sharp sense of time, people would be reduced to insensate messes, unable to move, talk, remember or learn.

“We don’t think about it, but just walking down the street is an exquisitely timed operation,” says neuroscientist Lila Davachi of New York University. Muscles fire and joints

steady themselves in a precisely orchestrated time series that masquerades as an unremarkable part of everyday life. A sense of time, Davachi says, is fundamental to how we move, how we act and how we perceive the world.

Yet for something that forms the bedrock of nearly everything we do, time perception

is incredibly hard to study. “It’s a quagmire,” says cognitive neuroscientist Peter Tse of Dartmouth College.

The problem is thorny because there are thousands of possible intricate answers, all depending on what exactly scientists are asking. Their questions have begun to reveal an astonishingly complex conglomerate of neural timekeepers that influence each other.

New findings hint that the brain has legions of assorted clocks, all tick-tocking at different rates. Some parts of the brain handle milliseconds and others keep track of decades. Some neural timers handle body movements; others monitor information streaming in from the senses. Some brain departments make timing predictions for the future, while timing of memories is handled elsewhere.

This diversity has led some scientists to focus on figuring

Distortions Drugs, disorders and emotions can stretch or shrink time, depending on the neural system they target. Studying these subtle timing deficits may help reveal how the brain detects and responds to time.

FULL SOURCE LIST IS AT
BIT.LY/SN_BRAINCLOCKS

	Time changers	Deficits
Drugs	Stimulants	Stimulant dependence makes it hard to distinguish durations and tap fingers to a beat
	Psilocybin	People taking this component of psychedelic mushrooms have trouble producing time intervals longer than a few seconds and are worse at tapping along with a slow beat
Disorders	Parkinson's	Finger tapping, repetitive wrist movements and timing seconds and subseconds become difficult for people with Parkinson's disease
	ADHD	People with attention-deficit/hyperactivity disorder can have trouble telling apart two lengths of time
Emotions	Fear	Scary movies such as <i>The Shining</i> and <i>Scream</i> have been shown to stretch time judgments
	Anger	People report that angry faces seem to last longer on a screen than faces with neutral expressions, even if the on-screen time period is the same

out how the brain stitches together the results from its many clocks to reflect the outside world accurately. A deeper understanding of how the brain's timekeepers work might also shed light on something much more profound: how the brain constructs its own reality. The brain sometimes squishes, expands or warps time, some studies suggest. Subtle timing slips have been linked to emotions, attention, drugs and disorders such as schizophrenia. Those tweaks hint at how the brain normally counts seconds and milliseconds.

Time warp

To the chagrin of people looking for simple solutions, there is no tiny clock tucked beneath the skull that marks the passing seconds, Tse says. And the brain's timekeeping is not always as reliable as the steady tapping of a metronome. Instead, time can sometimes be experienced as stretched out lulls followed by torrential bursts.

Most people have experienced this phenomenon firsthand. High-octane experiences can slow perception of time, flinging the world into slow motion. An out-of-control car careening toward the median or a skydiver's plummet toward the ground can cause time to apparently stretch, making the event seem longer than it actually was.

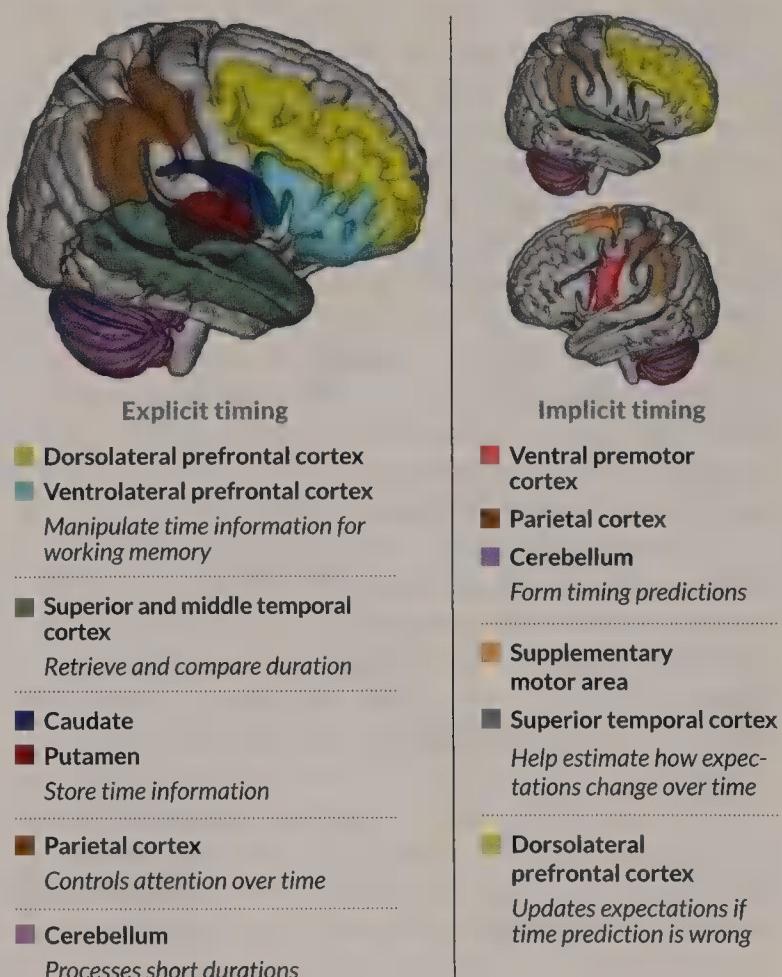
Time can be stretched even without risking life and limb. After just 10 minutes of meditation, people seem to perceive time as lasting longer than it objectively does, scientists reported in 2013. Emotions can also stretch or contract time. Looking at angry faces or scary spiders makes people think that time slowed, for instance. To further muddle matters, simply knowing that this link between emotion and time perception exists can weaken the connection, French scientists reported April 15 in *Consciousness and Cognition*.

Even something as simple as temperature can change time perception. Walking on a treadmill in a hot room for an hour seemed to make time speed up for men in one study. After an hour, participants clicked a computer mouse after 2.6 seconds when they were supposed to click it at three-second intervals, an effect that wasn't present when they were kept comfortably cool. After acclimating to the heat over a 10-day period, the men no longer misjudged time, scientists reported in the March *International Journal of Psychophysiology*. The results fit with older data suggesting that fevers can distort the perception of time.

Hallucinogenic mushrooms and drugs such as cocaine and LSD skew the brain's sense of time, as can certain disorders. Children with attention-deficit/hyperactivity disorder have trouble telling apart two lengths of time. Parkinson's disease can leave people with problems in timing seconds and subseconds. And even before symptoms appear, people with Huntington's disease have deficits in estimating passing time.

Brain injuries can also warp a person's sense of time, though such effects are almost always subtle — too subtle for patients to even notice, says cognitive neuroscientist Federica Piras of IRCCS Santa Lucia Foundation in Italy.

Brain time Some of the brain's multitude of timekeepers are listed below. Studies suggest that several brain areas handle aspects of explicit timing — when a person is asked to estimate a certain duration (left). Other areas (right, there's some overlap) are involved in implicit timing — making timing predictions for durations of events without being directly asked to do so.



Source MARY HAD A LITTLE LAMB

Quilt LADATLERY MB HA MA LIT

Stitched together By scrambling and carefully piecing together snippets of foreign speech (example in English for clarity) in a sound quilt, scientists found that a brain region called the superior temporal sulcus responded more strongly to longer chunks of sound. Fragment lengths were very small, ranging in length from 30 to 960 milliseconds.

The fact that so many diverse diseases, injuries, drugs and even bodily states can sway time perception serves as powerful evidence that timekeeping in the brain is not a monolithic entity. Instead, people rely on a diverse collection of clocks, each with a different job description.

Neurons keep a beat

Most, if not all, of the brain probably has the ability to sense and respond to time in some way, many researchers think. Time is baked into almost everything the brain does. Even in a dish, nerve cells, or neurons, can detect and respond to time information, scientists reported in March in the *Journal of Neuroscience*.

Nerve cells removed from a rat's cortex, the brain's outer layer, will respond in complex ways to the tempo of music, neuroscientist Antonius VanDongen of Duke-NUS Graduate Medical School Singapore and colleagues have found. After genetically engineering a network of nerve cells to respond to blue light, the team regaled the cells with "music" — carefully timed patterns of light based on the rhythm and notes of songs. Upon "hearing" the songs, the cells' electrical reactions could usually determine whether ragtime or classical music was playing at any given moment. And the cells got better as the seconds ticked by, hinting that they could hold a memory of the tempo information for about six seconds.

Those results show that time processing is fundamental in the brain, says VanDongen. "This is a very basic thing," he says. A small group of neurons is the building block that may enable more sophisticated time processing.

Of course, nerve cells don't usually live in lab dishes. The cells are housed in complex and diverse networks in the brain. Studies from human brain scans have also revealed clues about how the brain handles various aspects of time, suggesting roles for the cerebral cortex, the basal ganglia and the cerebellum. Activity in the insula (part of the cortex) changes when people are asked to estimate time by clicking a button at the end of an interval, for instance. And a recent study of people listening to snippets of foreign speech found a brain region, the superior temporal sulcus, that responds to increasingly longer sections of speech.

Neuroscientist Tobias Overath of Duke University and colleagues designed "sound quilts," long strings of speech made by stitching together shorter chunks ranging from 30 to 960 milliseconds. The superior temporal sulcus became more active as the chunks of sound quilt grew longer, brain scans revealed.

The findings serve as a good example of how the brain uses precise timing information as it merges disparate sounds into meaningful words. The results "are not overtly about time, or timing as such," says Overath. "But it's very compelling evidence of how time actually does play a role in something as important and fundamental to us humans as speech."

It's unclear what the individual neurons in the superior temporal sulcus are doing to track the lengthening sounds, Overath says. Brain scanning methods, like the fMRI used in the Duke study, don't have the resolution required to detect the behavior of single nerve cells. But studies on animals may provide clues about how some neurons keep time.

A recent study in rats offers a clear explanation of how some cells tick off the seconds. Rats were trained to press a lever for a sip of water. But the water would appear only after a certain amount of time had elapsed. The rats quickly learned not to waste their energy pushing the lever when it was too early, a behavior that revealed their timing abilities.

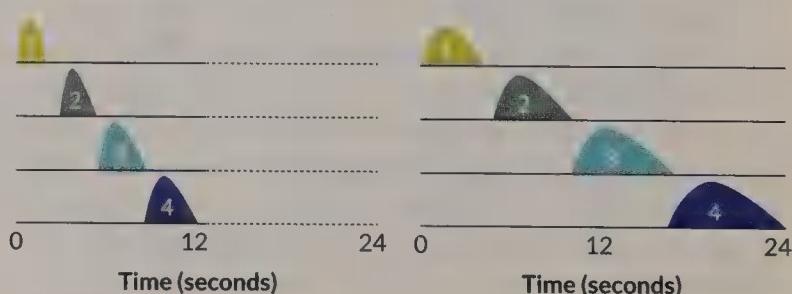
While the rats were timing the appearance of the water, neuroscientist Gustavo Mello of the Champalimaud Centre for the Unknown in Lisbon, Portugal, and colleagues eavesdropped with electrodes on neurons in the rats' striatum, a brain area thought to be important for time perception. Sure enough, the team found cells that fired off electrical signals in a sequence that spanned the entire waiting period, the team reported in May in *Current Biology*. These cells were keeping track of the seconds that ticked by.

What's more, many of the cells changed their behavior to remain in the right spot in their sequence even as the time intervals lengthened: A cell that always fired in the middle of a 12-second sequence would shift its behavior as the wait increased, firing around second 18 of a 36-second sequence, for instance.

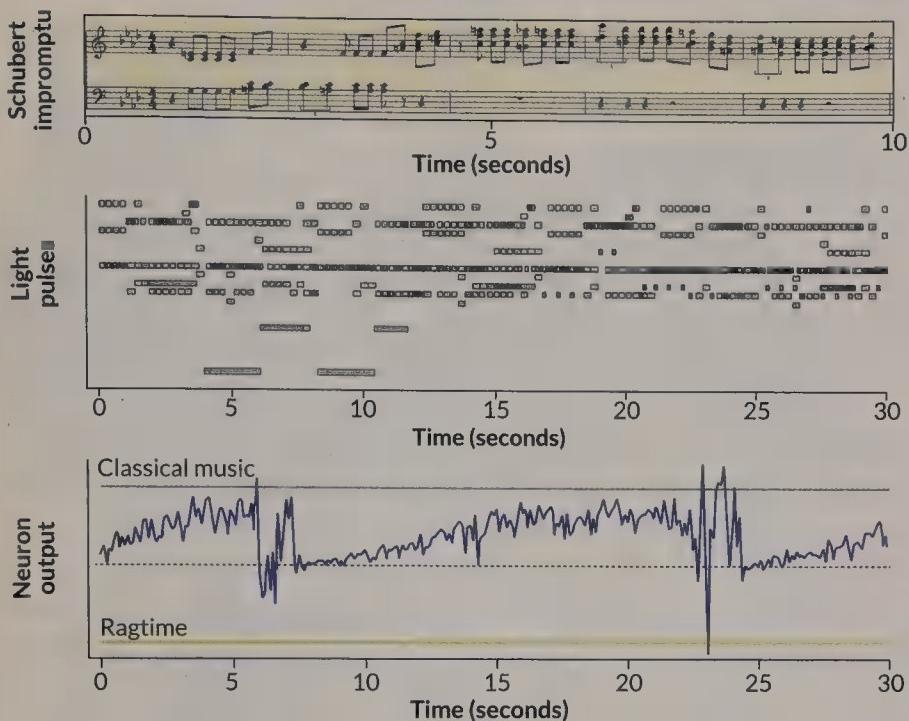
Mello likens these cells to rubber bands that can expand and shrink to fill the necessary time. "You can stretch it and compress it," he says. The results suggest that "the neurons are encoding relative time," not absolute time, UCLA neuroscientists Helen Motanis and Dean Buonomano wrote in a *Current Biology* editorial.

The results are exciting, but Mello cautions that this example might not generalize to other timekeepers. "We should be

Rubber band neurons Rat neurons (four represented below) in a brain area called the striatum mark time by firing off messages in a sequence (left). Their activity stretches (right) to fill a broader time slot as they need to count more time, but their firing order stays the same.



To hear a German language sound quilt, visit bit.ly/SN_BrainClocks



They got the beat In a dish, rat neurons engineered to respond to light can tell whether they're listening to classical or ragtime music, in part because of the different timing signals. Scientists converted a Schubert impromptu (top) into different patterns of timed light pulses (middle). As the cells "listened," their activity was able to detect that classical music was playing as opposed to ragtime.

very careful when making any statement about how the brain encodes or decodes time," he says. "Encoding in what conditions? In what range?"

Rips in the fabric

Some of the brain's clocks are known to keep time on different scales. For instance, the sound-processing system in the brain is much more precise when timing incoming signals than the visual system is, Overath says. That discrepancy between the senses is why CDs often include more than 44,000 segments of music per second, a number known as the sampling rate; videos often contain a mere 24 images per second. Yet the brain is still able to tie together those vastly different rates of information into an experience that makes sense, most of the time.

Even within the same system, the brain must actively manage timing signals. Imagine receiving simultaneous touches on the toe and on the nose, Tse says. It takes the toe touch tens of milliseconds longer to travel up the leg and body to reach the brain than the nose touch, yet you would perceive the two touches simultaneously. Your brain somehow knows to unite those two signals into a single event in time, even though they arrived at the brain separately.

The same sort of consolidation happens when watching TV. Although the sounds from the speakers don't sync exactly with the signals from the screen, we don't perceive a problem. Humans can tolerate about a fifth of a second of deviation between sight and sound before a bad dub becomes obvious.

The brain is able to knit different signals in time together into unifying experiences in what Tse calls a buffering process. Some type of a brain buffer collects data coming in over about

a quarter of a second and stitches it together into discrete events that we recognize as "now."

New work suggests that this process goes awry in people with schizophrenia, who often report time as a jumble. "It's actually quite fascinating," says neuroscientist Virginie van Wassenhove of INSERM in France. People with schizophrenia "describe their world as a movie that's segmented and they have to reconstruct the meaning of that movie, because time is not continuous for them."

When asked to make a conscious timing judgment, people with schizophrenia merge sights and sounds over a longer window of time than people without the disorder, according to research by van Wassenhove and her colleagues. Healthy people consciously combined sights and sound over a 200-millisecond window. For people with schizophrenia, that window stays open for around 300 or 400 milliseconds.

"In a way, a moment is consciously longer for them," van Wassenhove says. This longer-than-usual "now" applied only to timing tasks when the study's volunteers were explicitly asked to keep track of time, the researchers found. When not explicitly asked to pay attention to a timing task, healthy volunteers noticed timing discrepancies just as often as did people without schizophrenia. For example, a badly dubbed movie would be just as bothersome for both groups.

Those puzzling results hint at some profound differences in the way people with schizophrenia might process time, van Wassenhove says. Perhaps different neural systems are responsible for keeping track of time consciously and unconsciously, and those systems are affected differently by the disorder.

So far, scientists are struggling to make sense of these sorts of hints. But experiments are becoming more sophisticated as scientists attempt to mimic real-world scenarios. "In the real world, we don't have tunnel vision," says Warren Meck of Duke. "We're not timing just one thing at a time and ignoring other things." He and his colleagues are working on how brains keep track of multiple, simultaneous events. And new techniques to manipulate neurons will allow researchers to see if they can mimic time perception in the brain.

Other researchers are exploring concepts like musical rhythm, ordering events in time, and mental time travel, in which people imagine the past and the future. "All of these aspects are possible ways of approaching the big concept of time," van Wassenhove says. Scientists hope that these types of experiments will ultimately reveal how the brain makes and keeps its own time. ■

Explore more

- Federica Piras et al. "Time dysperception perspective for acquired brain injury." *Frontiers in Neurology*. January 13, 2014.



LIFE'S CYCLES

Poking holes in classic models of circadian
clock evolution **By Tina Hesman Saey**

The Earth has rhythm. Every 24 hours, the planet pirouettes on its axis, bathing its surface alternately in sunlight and darkness.

Organisms from algae to people have evolved to keep time with the planet's light/dark beat. They do so using the world's most important timekeepers: daily, or circadian, clocks that allow organisms to schedule their days so as not to be caught off guard by sunrise and sunset.

A master clock in the human brain appears to synchronize sleep and wake with light. But there are more. Circadian clocks tick in nearly every cell in the body. "There's a clock in the liver. There's a clock in the adipose [fat] tissue. There's a clock in the spleen," says Barbara Helm, a chronobiologist at the University of Glasgow in Scotland. Those clocks set sleep patterns and meal times. They govern the flow of hormones and regulate the body's response to sugar and many other important biological processes (*SN: 4/10/10, p. 22*).

Having timekeepers offers such an evolutionary advantage that species have developed them again and again throughout history, many scientists say. But as common and important as circadian clocks have become, exactly why such timepieces arose in the first place has been a deep and abiding mystery.

Many scientists favor the view that multiple organisms independently evolved their own circadian clocks, each reinventing its own wheel. Creatures probably did this to protect their fragile DNA from the sun's damaging ultraviolet rays. But a small group of researchers think otherwise. They say there had to be one mother clock from which all others came. That clock evolved to shield the cell from oxygen damage or perhaps provide other, unknown advantages.

The original biological timepiece may not have resembled the precision body clocks that scientists study today. The ancestral clock may have started out as simple as a sundial, researchers say, but it provided a foundation for building the more elaborate mechanisms that now control everything from blood pressure to bedtime.

Circadian clocks don't have gears and hands. They're composed of RNA molecules and proteins that oscillate in abundance. At particular

Throughout the human body, circadian clocks keep activities running on a daily schedule of day and night. New work is shedding light on the origin and evolution of biological clocks.

times of day, certain clock proteins switch on production of messenger RNA, used by the cell to bake fresh batches of

other clock proteins. Eventually levels of those proteins reach a certain threshold; they then shut off creation of the messenger RNA that produces them. The self-suppressing proteins disintegrate or get nibbled away by other proteins until their levels fall below a threshold, signaling the need for another batch, and the cycle starts again.

Just as Rolex, Timex, Swatch and Seiko make their own versions of a wristwatch, organisms including cyanobacteria, fungi, plants and insects have all invented their own varieties of circadian clocks. The cycling proteins are as different among these organisms as digital watches are from precision quartz clockworks. But all of them mark days with the predictable ebb and flow of messenger RNA and protein production.

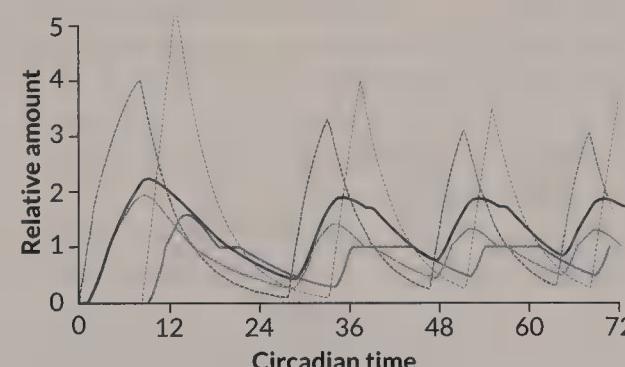
There's no doubt that today's circadian clocks are must-have accessories for most organisms living on Earth's surface. But does the run-away-from-the-light origin story make sense?

A main piece of evidence in favor of the "flight from light" idea is that cells tend to replicate their DNA at night safely under cover of darkness and repair it during the day as damage from UV light accumulates. Some of the same protein cogs that drive the circadian clocks are also involved in DNA repair, further solidifying the connection.

"That's a nice idea," says circadian cell biologist John O'Neill of the MRC Laboratory of Molecular Biology in Cambridge, England, "but it doesn't fit with modern data."

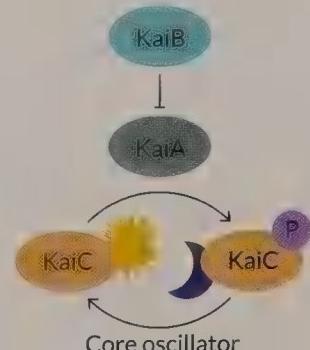
Going way back

Several lines of evidence argue against flight from light as the common force propelling the evolution of circadian clocks, says O'Neill, one of the scientists rewriting the circadian clock origin story.



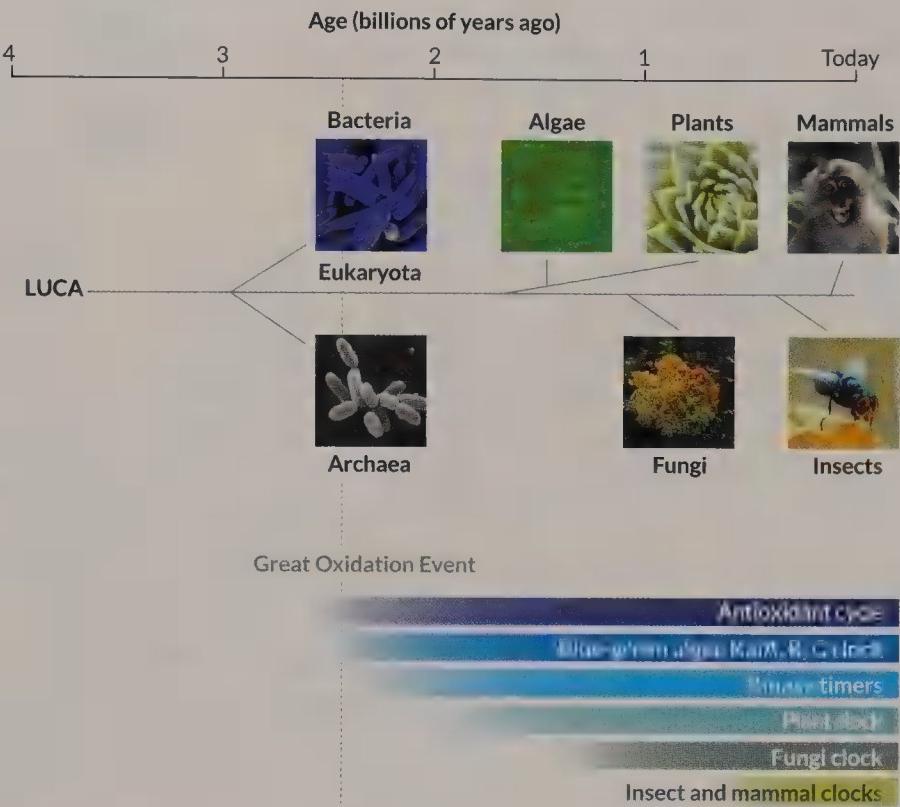
Roller coaster In fruit flies, amounts of circadian clock "gears," proteins (bold lines) and messenger RNAs (dotted lines), rise and fall at certain times of day. Three of the important gears, called Clock (purple), Timeless (gray) and Period (light blue), each peak and plummet once every 24 hours, as seen in this computer simulation. If nothing disturbs it, the clock will go on producing the waves of activity day after day.

SOURCE: CHEN LI ET AL/BMC SYSTEMS BIOLOGY 2010



Blue-green algae have one of the simplest circadian clocks, with three protein gears. KaiA helps KaiC add phosphate (purple) to itself by dusk. At night, KaiB blocks KaiA and the phosphates are stripped from KaiC by dawn. This clock helps algae synchronize photosynthesis with sunlight.

SOURCE: ANNA CHEN ET AL/SCIENCE ADVANCES 2015



Mother of all clocks

Some scientists think the last universal common ancestor, or LUCA, that gave rise to all domains of life had a primitive circadian timer.

That ancient timer may have been altered to meet environmental challenges, such as oxygen toxicity. Bars indicate how long certain circadian clocks known today have existed.

SOURCE: R. EDGAR ET AL./
NATURE 2012

If the cycle arose to protect DNA, one would expect cycling to happen only if there was DNA to protect. But circadian rhythms can happen in a test tube without DNA.

A type of cyanobacteria, or blue-green algae, known as *Synechococcus elongatus* has one of the simplest known circadian clocks. It consists of three proteins called KaiA, KaiB and KaiC. Those three gears, along with two accessory proteins, help the algae prepare for sunrise by stockpiling proteins needed for photosynthesis and other important daily activities.

Plop the three clock proteins into a test tube. Add energy from adenosine triphosphate (better known as ATP), and the clock will rhythmically add and subtract phosphate molecules from KaiC, Takao Kondo of Nagoya University in Japan and colleagues reported in *Science* in 2005. The finding shook up circadian researchers because it showed that clocks can operate without DNA. It also revealed that they don't need to switch messenger RNA and protein production on and off to keep time.

Those blue-green algae and the mysterious, unnamed ancestor of insects and animals formed different branches on the evolutionary tree more than 1 billion years ago. Clock proteins of *S. elongatus* are nothing like the central time-keeping proteins of mammals. So some researchers doubted that DNA-free clocks existed in organisms more complex than algae.

O'Neill and his collaborator Akhilesh Reddy

of the University of Cambridge thought that they could find DNA-free clocks elsewhere. They decided to look for circadian clocks in human red blood cells, which lack a nucleus where DNA is stored. Without DNA, there is also no messenger RNA production, which is essential for the classic circadian clocks to work. Nevertheless, the cells still have circadian rhythms, O'Neill and Reddy reported in *Nature* in 2011.

The red blood cell clock is entirely different from the protein and messenger RNA cycle that synchronizes nucleus-containing cells with the sun. In the red blood cells, antioxidant proteins called peroxiredoxins accept or give up oxygen molecules in a persistent circadian rhythm. Their action helps mop up hydrogen peroxide, a by-product of a cell's normal energy-manufacturing activities. Hydrogen peroxide and other oxidants can damage many components of a cell, so keeping them in check is essential for survival.

Peroxiredoxins are found in a wide variety of organisms, including marine algae called *Ostreococcus tauri*. Working with other collaborators, O'Neill and Reddy examined the peroxiredoxins in the algae. "Just like the red blood cells, there was a rhythm," O'Neill says. The amount of oxygen molecules clinging to the peroxiredoxins rose and fell in a persistent 24-hour cycle. The team reported that finding in the same 2011 issue of *Nature*.

A year later, the researchers reported in *Nature* that they had found peroxiredoxin cycles in fruit flies, the plant *Arabidopsis thaliana*, a fungus called *Neurospora crassa*, *S. elongatus* cyanobacteria and an archaeon called *Halobacterium salinarum*. Together, the organisms represent all of the major domains of life. If every domain has peroxiredoxin clocks, the antioxidants are most likely ancient, probably dating back billions of years.

The oxygen menace

No one knows for sure how far back those antioxidant clocks go, but O'Neill has a time frame in mind: 2.5 billion years. That's when cyanobacteria, which had recently begun using photosynthesis to fuel their activities, started releasing vast amounts of oxygen in the Great Oxidation Event. While photosynthesis and an oxygen-rich atmosphere are now considered necessities, oxygen was poison for Precambrian life-forms. Organisms that could not tolerate free oxygen either died or ended up in the anaerobic deep sea. "If they didn't die off, they had to cope," O'Neill says.

Oxygen would have been a problem mainly

during the day, when photosynthesis was taking place. Organisms that geared up their antioxidant defenses — stripping peroxiredoxin of oxygen molecules so that it could sponge up hydrogen peroxide when the sun peeked over the horizon — would get a jump on survival. A timing mechanism that could anticipate oxygen's arrival instead of just reacting to it would be "such an enormous advantage," says O'Neill, "that it just became hardwired."

Peroxiredoxins themselves are not clock gears. They are more like a clock's hands; the amount of oxygen bound to them is an indicator of time being kept by an as yet unknown and even more ancient central timekeeper. That mysterious clock was such an advantage that organisms have maintained it across evolutionary history, tinkering with it as needed. Like watches that can tell time in several time zones and display a.m. and p.m. plus calendar information, circadian clocks have added components to keep track of different environmental challenges, O'Neill speculates.

Other researchers have proposed that because the circadian clock proteins of cyanobacteria, animals and plants are so different, ancestors of those organisms must have evolved clocks independently. But even though the core cogs are different, says O'Neill, "you always find the same handful of kinases that set the speed of the clock."

Kinases are proteins that tack phosphate molecules onto other proteins, slating them for destruction or altering their function. Two of the most important of those kinases — casein kinase 1 (CK1) and glycogen synthase kinase 3 (GSK3) — are also important in pacing peroxiredoxin clocks, O'Neill has found. They may be the ancestral clocks he and others have been seeking.

Even organisms that don't have circadian rhythms have kinase-driven peroxiredoxin cycles, O'Neill, Helen Causton of Columbia University and colleagues reported in the April 20 *Current Biology*. Baker's yeast, *Saccharomyces cerevisiae*, has neither proteins recognizable as clock proteins nor a 24-hour cycle. That doesn't mean yeast can't keep time. They have about eight three-hour-long respiratory oscillations in which their rate of oxygen consumption rises and falls. Chemically blocking yeast's version of CK1 slows down the yeast oscillation. Messing with CK1 also alters the circadian rhythm in mouse cells, the researchers reported.

Those findings suggest that kinases are important for establishing the rhythm of circadian timers.

The researchers think the kinases may have formed a simple timer, similar to cyanobacteria's KaiA, B, C system. With those simple gears in place, organisms would have added more gears to form the clocks we see today, O'Neill says. There is still no evidence, however, that the kinases are the ancestral molecules that spawned today's clocks.

O'Neill admits that there is another possibility. There may be no mother clock. Cell biology may simply be driven by biochemical reactions that naturally fall into rhythmic patterns. "I don't like that possibility because it's quite difficult to disprove" or test, he says. The only real way to demonstrate that's not the answer is to go back and find the master clock. But, O'Neill laments, "the problem with all these evolutionary arguments is you can't test them without a time machine."

"The problem with all these evolutionary arguments is you can't test them without a time machine."

JOHN O'NEILL

Independent evolution

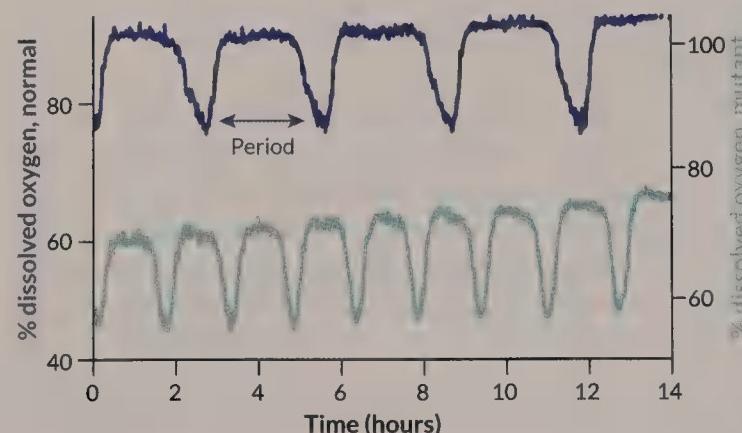
Not everyone is enamored with the peroxiredoxin hypothesis. "They have a very grandiose scheme," says Joseph Takahashi, a circadian geneticist and neuroscientist at the University of Texas Southwestern Medical Center in Dallas. "There's just no evidence."

True enough, acknowledges O'Neill. "We don't have a mechanism." All they have are observations that are incompatible with classic models that describe clocks as machines of oscillating proteins and messenger RNA that evolved as light-avoidance mechanisms.

Central to O'Neill's argument is the idea that there must have been an ancestral clock upon which all clock-carrying organisms built their daily timers. Other researchers aren't so quick to

Precision timing Kinases are enzymes that may have been gears in the original circadian clock. Today they act as pacemakers for many biological timers. A kinase called Swe1 sets the pace of oxygen consumption cycles in baker's yeast. One cycle usually lasts about three hours (top line), but a mutation that removes Swe1 speeds up the cycle (bottom line).

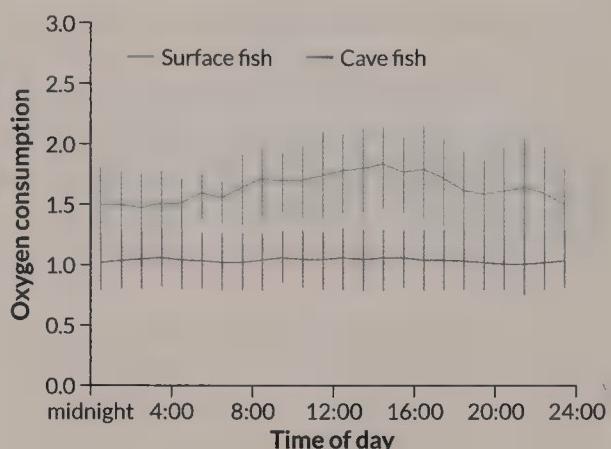
SOURCE: H. CAUSTON ET AL/CURRENT BIOLOGY 2015





Saving energy Eyeless Mexican tetra (above) live in dark caves, but their circadian clock always registers day. The one-tock clock saves the fish energy by keeping oxygen consumption steady (bottom line, in graph) compared with the clocks of Mexican tetra that live in surface waters and increase oxygen use during daytime hours (top line).

SOURCE: D. MORAN ET AL/PLOS ONE 2014



dismiss independent evolution.

"I don't think we should assume it's hard to build a clock," says Susan Golden, a microbiologist at the University of California, San Diego. The timing mechanisms seen in nature today are just the ones that have stuck around. Organisms may have tried and rejected other timers or other rhythms. Recently, independent research groups found that a marine worm has a lunar clock, and a sea louse has a tidal timer (*SN: 11/2/13, p. 6*). Golden's lab group is tinkering with a cyanobacterial circadian clock to see if it can keep time on a different scale — weeks or hours instead of days, for instance.

Real-world advantages

Although no one has dug up the original clock, some scientists are philosophizing about why such a mechanism might have been useful in the first place. Avoiding oxygen toxicity and fleeing damaging light aren't the only reasons a circadian clock is a good idea. Some researchers say the advantage of having a clock may be in keeping contradictory chemical reactions separated or making cells run more smoothly by creating a production schedule for molecules needed for each step of a biochemical chain reaction.

"We wonder why is the clock turning on and off metabolism each day rather than just letting everything run with the taps on," Takahashi says. He and colleagues are testing the idea that producing things in big bursts the way the clock dictates is more energy-efficient than making small amounts over a longer period. One 2010 computer simulation estimates that circadian clocks may save organisms enough energy to grow 15 percent faster. Measuring that possible advantage in the real world, however, has been difficult.

Physiologist Damian Moran of the company Plant & Food Research in New Zealand found a natural experiment already in progress that

proved to be a good test of the energy-saving idea. Moran and colleagues in Sweden studied fish called Mexican tetra (*Astyanax mexicanus*) to learn how energetically expensive vision is. One version of the fish swims in surface waters. Another version, from the Pachón caves in north-eastern Mexico, lives in constant darkness and has no eyes. The cave fish have altered circadian clocks that are permanently jammed as if it were daytime.

Moran put the surface and cave fish in swimming tubes and flowed water over them so that they swam at "a slow walk" for several days. He measured how much oxygen the fish used. As expected, the surface fish used more oxygen during the day than at night. But the cave fish used the same amount of oxygen day and night. "Maybe it's just that one fish," he recalls thinking. "So then we put the next fish in." That fish's oxygen consumption stayed flat, too.

By keeping their metabolism at a steady rate all day, rather than a rhythmic boost that follows light cycles, the cave fish saved 27 percent of their energy, the team reported last September in *PLOS ONE*. When both surface and cave fish were tested in darkness, cave fish did even better, expending 38 percent less energy than surface fish did.

The finding doesn't mean Takahashi is wrong about circadian clocks saving energy in a rhythmic world. It's just that cave fish live in a fairly constant — dark — environment. In that case, wonders Moran, "what are you rousing your metabolism for?" If fish gear up in anticipation of an event, "and it doesn't happen, what a waste," he says. But in a world where sunrise is the gold standard of predictability, circadian clocks may indeed be thrifty options.

Just because some animals in extreme environments have radically different clocks doesn't mean that living without rhythm is a good idea for everybody. "I'm rather skeptical that — except in some freaky situations — life is better without a clock," says Helm, the chronobiologist from Glasgow. Cave fish also lack eyes, but nobody would argue that means eyes are unimportant, she says.

Maybe, says Golden, clocks didn't evolve for just one reason. Clocks, she says, may generally be necessary for "not being jerked around by the environment."

Explore more

- Genetic Science Learning Center. "The time of our lives." bit.ly/Clockgenes

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BOOKSHELF

How English became science's lingua franca



Scientific Babel
Michael D. Gordin
UNIV. OF CHICAGO, \$30

When the Russian chemist Dmitri Mendeleev discovered the “periodic law” that he illustrated with a table of the elements, he published his finding first in Russian and then in a German translation. Shortly thereafter, though, the German chemist Lothar Meyer claimed to be first to perceive the periodicity in the properties of the elements when ordered by atomic weight.

Meyer had seen Mendeleev’s paper. But in it, “periodicity” had been mistranslated as “phased,” leading Meyer to believe Mendeleev hadn’t noticed how similar properties recurred periodically. For decades, dispute raged over who deserved credit for the periodic law.

Now, almost 150 years later, it seems like a trivial argument. But it serves as an excellent entrée for *Scientific Babel*, Princeton historian Michael Gordin’s perceptive account of the historical role of language in science. Today’s language of science is English, much as a few centuries ago it was Latin. But between then and now, various tongues — notably German, French and even Russian — have competed with English for supremacy in the realm of scientific communication.

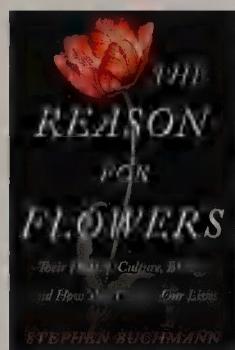
Language, Gordin contends, shapes not only how science is communicated but also how it is done. Science education,

journal publishing, international collaborations and various other aspects of the scientific enterprise are colored by issues intermixing language with war, politics and economics.

All those factors in turn play into the present-day dominance of English. As Gordin notes, no single factor can explain that situation, but American political and economic power certainly played a role comparable to that of America’s scientific prowess. And English’s rise is also partly due to the decline of German science, weakened by World War I and then devastated by Nazi ideology.

After World War II, Russian emerged as an important science language, so much so that massive commercial translation efforts were undertaken to make research published in Russian accessible to American scientists. Scientists who spoke other languages found it more convenient to buy the English translations than to learn Russian itself, demonstrating how economic factors contributed to the English takeover of science everywhere.

Gordin’s scholarly assessment of these matters will not have Hollywood entrepreneurs scrambling for movie rights. But it is insightfully and engagingly written, a masterful mix of intelligence and style. He illuminates an important side of science with academic rigor, but without a trace of academic obfuscation. It’s a very pleasant example of the skillful use of language. — Tom Siegfried



The Reason for Flowers
Stephen Buchmann
SCRIBNER, \$26

BOOKSHELF

Flowers in ecosystems and economics

In the art of seduction, flowers have few equals. With sweet nectar and protein-packed pollen, some blooms lure bats and lizards as well as the proverbial birds and bees to play unwitting roles in fertilization. Other flowers, which evolution has sculpted to mimic potential mates of credulous insects, merely inspire frustrated desire among pollinators.

Over the last 130 million years or so, flowers have evolved from pollen-making pipsqueaks about a millimeter across to include blossoms that are large, showy and fragrant. Scientists have identified some 250,000 species of flowering plants, pollination ecologist Stephen Buchmann writes in *The Reason for Flowers*. About two-thirds of those species are endangered or threatened, mostly because of habitat loss but also thanks to climate change.

Buchmann does much more than chronicle the evolution of flowers since the dinosaur era. He explores the myriad roles that blossoms play in the human realms of art and

literature as well as in food and the economy.

The fruits and seeds of animal-pollinated flowers account for about one-third of the average human diet, Buchmann reports. Flowers are also big business: Worldwide, about 15 billion stems make their way to buyers each year. More than half pass through the most sprawling building in the world, a hangarlike facility near Amsterdam. The building covers more than half a square kilometer and hosts auctions processing about 21 million flowers each day. Breeders can easily spend \$100,000 bringing a new variety of flower to market; those striving to create a holy grail of blossoms such as a truly blue rose may spend millions.

The Reason for Flowers is a riveting account of the science, history and culture surrounding blooms since the dawn of humankind. Besides inspiring myths and perfume manufacturers, flowers have fueled economic manias that rival the dot-com bubble of the late 1990s: During the height of tulip enthusiasm in the Netherlands in the 17th century, purchasing a tulip could cost more than hiring a famous Dutch artist to paint its image. — Sid Perkins

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SOCIETY UPDATE



Reflecting on the future of *Science News*

My first anniversary as president and chief executive officer of Society for Science & the Public and publisher of *Science News* is rapidly approaching, and I wanted to take a moment to share some of the successes and the challenges we have faced this year.

The first thing I want to share is my gratitude to you, as members of the Society and *Science News* readers. When I joined the Society, I was told our readers were a loyal group of dedicated science enthusiasts and practitioners, but I am overwhelmed by your recent displays of commitment toward the future of this publication.

In a reader survey completed earlier this year, 79 percent of our paid readers said that they "definitely will" renew their *Science News* subscribing membership. That's a testament not only to your loyalty, but to the fine work Editor in Chief Eva Emerson and her terrific staff of science journalists, designers and producers do on a daily basis in print and online.

Many of you also did something quite remarkable this year. For the first time, we asked *Science News* subscribing members to consider becoming donors to the Society for Science & the Public. I am overwhelmed by the level of generosity and commitment to the cause of excellent science journalism that you have shown. Your donations help us to produce all the quality publications in the *Science News* Media Group, including our free online *Science News for Students* publication, as well as

supporting the Society's science competitions and education efforts.

I'm sure most of you know how difficult it is to maintain a high-quality news operation these days. All publishers are struggling to survive in the digital age, as subscription and advertising revenue continues to decline and people increasingly get their news from social media feeds free of charge.

Our own decline in subscribers has largely tracked that of other general interest newspapers and magazines. At its height in the late 1980s, *Science News* had a paid circulation of almost 250,000. Since then, print circulation has fallen steadily, to 225,000 in 1991, 135,000 in 2006 and 94,000 today. Along the way, production costs have continued to rise, yet we've managed to maintain our commitment to providing you with concise, current and comprehensive news. As a result, our publishing efforts have had an annual operating deficit for several years. We are working on multiple ways to reduce our anticipated 2015 losses through smart cost-cutting and new revenue initiatives.

In recent years, our editorial and technology teams have worked hard to make sure new and longtime readers can enjoy *Science News* in any format they choose. Our award-winning website, sciencenews.org, redesigned nearly two years ago, looks terrific on mobile devices and tablets and now averages more than a million visits every month. And our social media audience has grown to more than 2 million *Science News* fans on Facebook, up from fewer than 100,000 in 2013, and 1.4 million followers on Twitter.

But new readers do not instantly bring new revenue.

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SOCIETY UPDATE

Our real challenge, as it is for many publishers, is to convert casual readers of our free online news updates and blogs into subscribing members and donors who want to read and support *Science News*' premium features and news stories. Our donor campaign was one way to fill our revenue-expense gap. And we are moving forward on other fronts as well, including:

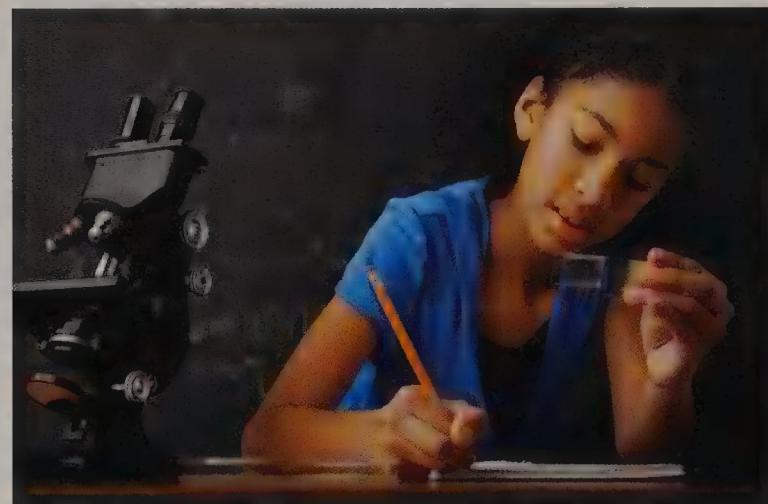
- Exploring ways to give online readers more options when paying for *Science News* content, including digital-only offers and the ability to purchase one article at a time.
- Discussing partnerships with publishers in the United States, China, Japan, Taiwan and South Korea that would include producing print and e-book compilations of *Science News* and *Science News for Students*.
- Renewing our emphasis on improving the number and quality of advertisers you see in *Science News*, both in print and online.
- Reaching out to philanthropists who share our commitment to excellence in journalism.

Perhaps the most exciting new program I want to tell you about is *Science News in High Schools*. The idea is simple: For \$500, an individual or an organization can sponsor any high school's subscription to *Science News* in print and online. Through this program, an entire school can enjoy full online access to sciencenews.org, including its archives of articles going back to 1924. Ten print copies of each issue of *Science News* would be delivered to the school's library and science teachers for the school year.

We are thrilled to be announcing our new corporate partners in this program later this summer. These partners are sponsoring schools in specific geographic regions and helping us launch this effort for the 2015–2016 academic year. Our plans include rolling out the program to schools across the country and enabling teachers to ask for *Science News* sponsors on classroom-funding websites like DonorsChoose.org and ClassWish.org.

This high school program is core to the Society's mission to promote human advancement through science. But we have another interest as well: Today's students are tomorrow's loyal readers — and supporters — of *Science News*.

I will keep you updated on how these efforts, and others, are going over the next six to 12 months. We believe *Science News* can and will achieve the financial sustainability it needs to thrive for decades to come. But we need your help and support as we work together to keep *Science News* around for the next century. Public understanding of science is simply too critical to our well-being at the community, national and global levels. Publications like *Science News* must continue providing cogent explanations of the most recent scientific discoveries. — Maya Ajmera



What teachers say about *Science News* in High Schools

"*Science News* would be a great resource instead of some of the resources my students choose. If I had access and it was easy for students, they may choose this instead of unreliable sources."

BIOLOGY TEACHER, DOUGLAS COUNTY, COLO.

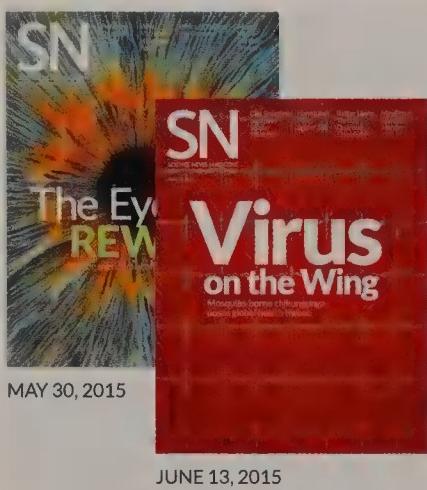
"I have purchased *Science News* from my own funds for several years. Any help is appreciated to get new materials into the hands of these students."

SPECIAL NEEDS SCIENCE TEACHER, GAGES LAKE, ILL.

"I have seen and used your publication previously. Submitting through the budget process each year is a bit cumbersome. This would be great."

SCIENCE TEACHER, JOHNSTOWN, PA.

Quotes are from an April 2015 SSP survey of 737 science teachers.



SOCIAL MEDIA

A virus goes global

Nathan Seppa's "Chikungunya is on the move" (SN: 6/13/15, p. 16) explained how the tropical virus is creeping into cooler climates, carried by mosquitoes. Readers on Facebook shared their own encounters with chikungunya.

"I got this late last year. There was no treatment at the time, and I am still feeling it from time to time. Your joints feel like they are broken, literally."

Benedict Beharry

"It was starting to hit St. Thomas really hard right before I moved off the island (August 2014). So many people I know became crippled with illness. Some of them still have joint pain."

Laura Dennen

"My sister is just recovering from this and says it was much worse than dengue."

Rebecca Weissinger

Join the conversation

E-MAIL editors@sciencenews.org

MAIL Attn: Feedback
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Connect with us**Inside the eye**

A new technology called optogenetics may help restore sight for some blind people. In "Seeing the light" (SN: 5/30/15, p. 22), Tina Hesman Saey explained how scientists are recruiting nerve cells in the eye to act as light detectors.

Reader Steve Schlosser thought the light-processing machinery of the eye's retina sounded just a bit backwards. "It would seem that the ganglion cells — which 'have long tails that bundle together to become the optic nerve and send messages to the brain' — would be the final section of the eye, not the first one that intercepts light. But the commentary and the diagrams all show the ganglions first, the bipolar cells second and the rod and cone cells as last."

It seems intuitive that light should encounter the ganglion cells last, says Saey. But the retina in mammals is set up so that light encounters the ganglion cells first and the light-detecting rods and cones last. Humans, other primates and some other animals work around the setup with the help of a structure called the fovea, in which the bipolar and ganglion cells have been moved out of the way so that the rods and cones are first in line to receive light. Humans take advantage of this by cramming the fovea with cones, which give sharp day vision. Rods, which allow night vision, ring the periphery. People constantly move their eyes so that the fovea scans the visual field, taking split-second snapshots that the brain stitches together into streaming video.

Early Earth was hot, hot, hot

Billions of years ago, Earth's oceans endured blistering temperatures thanks to incoming asteroids. The aftermath of these collisions may have shaped the evolution of the planet's first organisms, Thomas Sumner reported in "Impacts may have boiled early seas" (SN: 6/13/15, p. 12). "So, archaea dwelling near super-heated volcanic vents would definitely have a selective advantage for surviving a catastrophe like this," wrote commenter bruzote. "Heck, would they

even notice?"

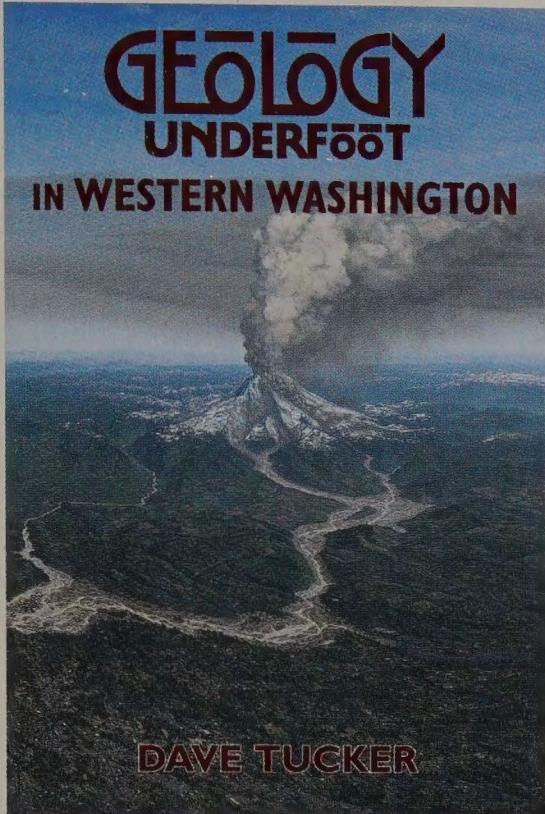
Organisms that thrive in hot environments, known as thermophiles, would have fared better than anything that needed lower temperatures, says Sumner. "Also, anything that lived deep in the oceans or underground probably wouldn't have noticed anything change at all. The scorching temperatures were confined mostly to the atmosphere and surface."

The mammoth in the room

In "How scientists will (or won't) bring back extinct species" (SN: 6/13/15, p. 27), Allison Bohac reviewed *How to Clone a Mammoth*, a book that explores the process of reviving long-gone animals with genetic engineering.

Some readers couldn't wait to welcome mammoths back into the world. "This would be awesome!" exclaimed **Rosie Trujillo Miller** on Facebook. But not everyone was excited. "I do not think that just because we may have the capability to create certain species that it is a good idea. No one, honestly, has any idea what the consequences of that might really be, no matter how much research has been done," wrote **Rebecca T.** Reader **Anna Grig** asked, "What would be a reason, apart from scientific curiosity, to clone just one piece of an environment that we know so little about?"

Despite concerns, some readers saw a lot of potential in the research. Working to bring back extinct species might provide useful information about genetics and gene manipulation, wrote commenter **Nas**. "All in all, it could lead to a huge step forward in science, specifically medical sciences." Reader **Tim Cliffe** agreed, adding: "The article points out something that many people don't know: Mammoths and the other Ice Age megafauna helped to create the ecologies in which they lived, and they could conceivably do so again. I feel that there is an additional reason — in all probability, we are responsible for having exterminated these creatures, and we ought to try and correct that mistake."



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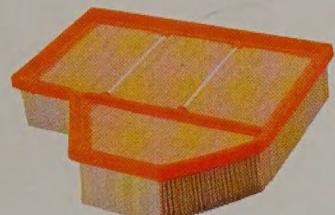
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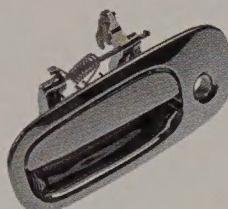
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Genetic switch wipes out tumors in mice

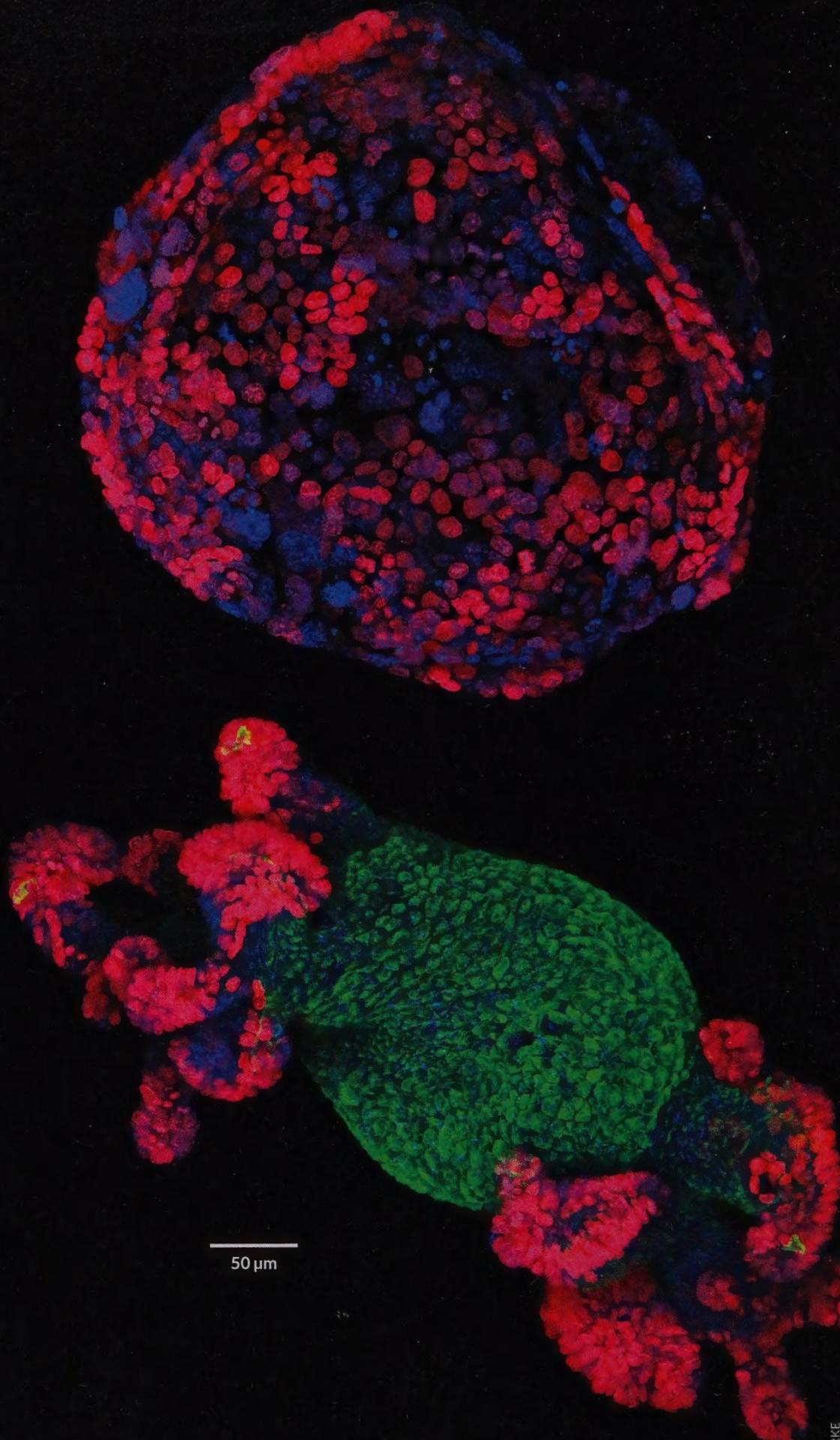
The gene *Apc* is like a club bouncer: It keeps cellular parties from growing out of control. By switching *Apc* on, researchers turned swelling mobs of mouse cancer cells (above) back into normal intestinal tissue (below).

Scientists knew *Apc* was involved in stifling tumor formation because most colon cancers find a way to turn the gene off. Lukas Dow, a cancer biologist at Weill Cornell Medical College in New York City, and colleagues investigated *Apc*'s role by genetically engineering mice with a kind of *Apc* on/off switch.

Shutting the gene off made puffy polyps bud in the animals' colons, the researchers report in the June 18 *Cell*. (The images show cells extracted from the mice.) Switching *Apc* on again made the frenzied cells morph back into healthy gut tissue, which contains intestinal cells (below, green) and clusters of stem cells (below, pink). The polyps disappeared.

Apc quiets signals that rev up cell growth, Dow says. Without the gene keeping growth signals under control, cells go berserk. Eventually, they can get aggressive and muscle their way throughout the body, he says. "And that's what kills patients."

If scientists can dial down growth signals in human colon cancers, Dow says, tumors may wither away — just as they did in mice. — *Meghan Rosen*



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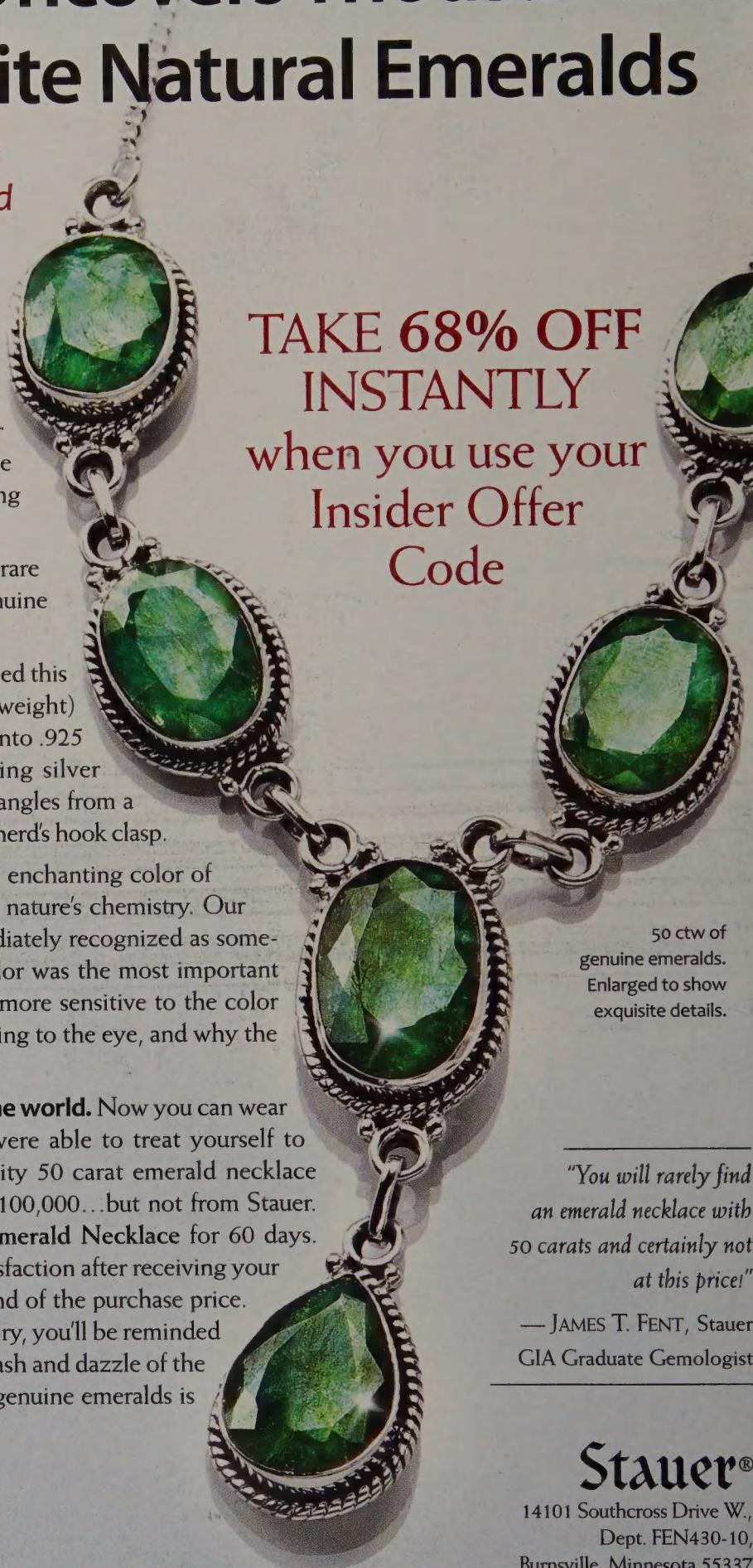
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